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# Contrasting deficits on executive functions in Chinese delinquent adolescents with attention deficit and hyperactivity disorder symptoms and/or reading disability

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ABSTRACT

Many studies reported high prevalence of reading disability (RD) and attention deficit hyperactivity disorder (ADHD) among delinquent adolescents. Very few have examined their cognitive profile. The present study compared the executive functions (EFs) and severity of delinquency in delinquent adolescents with RD and/or ADHD symptoms (AS). Delinquents with AS ($n = 29$), RD ($n = 24$), comorbidity AS + RD ($n = 35$) were recruited from juvenile institutions along with typically developing controls ($n = 29$) from local schools; all completed EF assessments and self-report questionnaires on delinquency. Results showed that pure AS group exhibited impaired inhibition while the pure RD group was weak in processing speed and visual memory. The comorbidity group showed unique impairments in interference control and significantly higher delinquency severity. The present findings suggest that comorbidity AS + RD may influence delinquency severity. It also provides a more comprehensive picture of the unique EF deficits associated with different groups, allowing for better matching for future identification and intervention programme.



## 1. Introduction

### 1.1. Background

Adolescence is a time of increasing challenges as well as vulnerabilities, and this may be particularly true for adolescents with special developmental needs. Studies conclude that attention deficit and hyperactivity disorder (ADHD) and reading disability (RD) are over-represented in juvenile prisons (e.g. Langhinrichsen-Rohling, Rebholz, O'Brien, O'Farrill-Swails, & Ford, 2005; Maniadaki, Kakouros, & Karaba, 2010; Shelley-Tremblay, O'Brien, & Langhinrichsen-Rohling, 2007).

For many years, studies have been carried out to identify the links between delinquency and RD (e.g. Kirk and Reid, 2001). Healy and Bronner (1936) first discovered that 52% of young male delinquents show symptoms of RD. Other international studies yielded similar results. A study by Morgan (1996) discovered that up to 52% of delinquents show symptoms of RD. Moreover, study in Sweden (Selenius, Dåderman, & Hellström, 2006) reported almost 40% of male delinquents as having

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RD. Furthermore, a similar study in the UK also suggests that more than 50% of its young offenders fulfil the criteria for RD (DA, 2005).

On the other hand, numerous studies from the United States and Finland find that delinquent populations display high prevalence rates of ADHD at 72 and 50% respectively (e.g. Haapasalo & Hamalainen, 1996). In a German study with male juvenile offenders, the prevalence of full clinical pictures of ADHD according to DSM-IV is 45% (Rösler et al., 2004). Nevertheless, studies from other countries such as the Netherlands and Belgium report relatively low prevalence rates of ADHD among young delinquents at 14 and 19% (Doreleijers, Moser, Thijs, Van Engeland, & Beyaert, 2000). The broad range of results emerging from different studies may be due to different criminal law systems and different diagnosis criteria for the two disorders.

To fully understand the relationships between ADHD, RD, and delinquency, researchers should look to a common impairment between them. Recent evidence shows that delinquent behaviours relate largely to executive function (EF) deficits, (Blair, Colledge, & Mitchell, 2001; Morgan & Lilienfeld, 2000), which impair the ability to maintain appropriate problem-solving set for goal-directed behaviour (Barkley, 1997; Pennington & Ozonoff, 1996). EF is an umbrella term encompassing a diverse range of cognitive processes (Shallice 1988; Stuss & Benson, 1986; Stuss & Knight, 2002). Despite the disagreement found in the conceptual framework of EF, EF impairments have been consistently established as important risk factors for the development of delinquent behaviour, and are hypothesized to increase the risk of engaging in delinquency (Ishikawa & Raine, 2003; Seguin, 2008).

ADHD is most frequently associated with EF deficits (Barkley, 1997, 1998; Quay, 1997), particularly in terms of deficits in response inhibition (Barkley, 1997). People with RD, in contrast, often exhibit more difficulties in language-related EF: although phonological processing deficits are a core feature of RD among readers of alphabetic languages (e.g. Adams, 1990; Wagner, Torgesen, & Rashotte, 1994), logographic languages (where characters are meaning-based), such as Chinese, mainly have problems in orthographic-related processing and morphological awareness (Ho, Chan, Tsang, Lee, & Luan, 2004; Shu, McBride-Chang, Wu, & Liu, 2006).

ADHD and RD are often comorbid (Willcutt & Pennington, 2000; Willcutt, Pennington, & DeFries, 2000) with a rate from 15% to 40% reported nationally (e.g. Pisecco, Baker, Silva, & Brooke, 2001). Individuals with comorbid ADHD and RD are at higher risk of disruptive behaviours (Willcutt & Pennington, 2000) and impulsivity than people with pure disorders (Purvis & Tannock, 2000).

Currently, three major hypotheses reign, and they are mutually exclusive. Early studies proposed the 'phenocopy hypothesis', suggests that one disorder could produce symptoms of the second without the cognitive deficits associated with that second disorder. Pennington, Groisser, and Welsh (1993) found that the comorbid group had a cognitive profile similar to that of the RD group in phonological processing but lacked the EF deficits characteristic of the pure ADHD group. However, later studies failed to replicate this result (e.g., Nigg, Hinshaw, Carte, & Treuting, 1998; Seidman, Biederman, Monuteaux, Doyle, & Faraone, 2001; Willcutt et al., 2001). Later researchers came up with the 'shared aetiology hypothesis', wherein children with pure RD or ADHD will show distinct patterns of cognitive deficits and both forms of deficit will co-occur in the comorbid condition. There is some support for this: Willcutt, Pennington, Olson, Chhabildas, and Hulslander (2005) showed that pure ADHD is associated with inhibition deficits, pure RD with deficits in phoneme awareness and working memory and comorbid group showed greater impairments on every measure administered. The final hypothesis is the 'cognitive subtype hypothesis', which argues that the cognitive deficits of the comorbid group are unique impairments caused by the interaction between the two disorders (de Jong, Oosterlaan, & Sergeant, 2006). The most recent findings appear to support this hypothesis, with unique deficits caused by comorbid ADHD + RD including impairments in working memory and rapid naming (Bental & Tirosh, 2007; Rucklidge & Tannock, 2002). In summary, previous studies have proposed multiple pathways to explain the co-occurrence of the two disorders, but no consensus has been reached.

### *1.2. The present study*

The present study has three objectives. The first objective was to examine the neuropsychological characteristics of a juvenile sample with ADHD symptoms (AS), RD and comorbidity AS + RD in a series of EF domains and the three hypotheses would be compared and examined. Based on previous research findings, we expected that AS would be associated with a pronounced deficit on inhibition, while RD would be associated with weaknesses on EF related to linguistic processing. For the comorbid group, in accordance to most recent researches on cognitive subtype hypothesis, we hypothesized that this group would exhibit a unique set of cognitive impairment that would not be expected based on the additive combination of the pure groups. The second objective was to determine the impact of comorbidity by comparing the delinquency outcome among the three study groups. We predicted that the comorbid group would have the poorest delinquency outcome in terms of both onset and severity than pure groups. This expectation was based on previous researches proposing that the comorbid AS and RD group was at the highest risk of disruptive behaviours and exhibits significantly more antisocial behaviours than pure groups. Thirdly, the present study would also investigate how well EF deficits predict different delinquency outcomes. Due to inconsistent findings about the link between EF deficits delinquency outcomes in past studies, we did not formulate specific hypotheses on this objective.

## 2. Method

### 2.1. Participants

Due to dominating ratio of boys in populations with ADHD and RD (Yoshimasu et al., 2010), only boys were recruited. Participants were 117 boys between 12.42 and 18.17 years of age (M = 14.93; SD = 1.05) who were divided into four groups: AS ($n$ = 29), RD ($n$ = 24), AS + RD ($n$ = 35), and control ($n$ = 29). It should be noted that there are totally six juvenile institutions in Hong Kong, and participants in the three study groups were recruited from five of them comprising one Children and Juvenile Home and four Schools for Social Development (SSD). The Children and Juvenile Home is the only government institution that provides temporary custody and residential training to young offenders according to the directions of the courts. SSD are special schools for students with moderate to severe behavioural and emotional problems. These problems include behavioural problems at school, psychological problems, family problems as well as delinquent behaviour.

Participants in the AS, RD and comorbidity AS + RD groups have history of delinquent behaviour. 217 delinquent boys who obtained parental consent were screened. Participants of the control group were matched in age, gender, grade and socio-economic background and were recruited from local secondary schools. Control group was recruited after all delinquent samples were screened and assessed in order to match the demographic composition (i.e. socio-economic background) of the delinquent sample. These control participants went through the same diagnostic procedure as the other three groups with the disorders to confirm the absence of problems in attention, behaviour and reading. All of the participants speak Cantonese as their first language, have normal intelligence, and no suspected brain damage, neurological, sensory, or other psychiatric disorders. None of them was taking medication while being tested.

### 2.2. Procedures

The study consisted of two phases: screening and assessment. During the screening phase, participants were administered a standardized subtest primarily to rule out intellectual disability. In screening for RD, cognitive and literacy tests were administered. In screening for AS, subscales on ADHD problems were administered. Only participants identified as having AS, RD, or comorbidity of the two disorders were selected for the assessment phase. During the assessment phase, five EF tasks were administered individually in a fixed random order. Participants completed a questionnaire on demographic background and delinquent behaviours.

All assessments were conducted by well-trained research assistants. All parents and adolescents gave their informed consent to participate in the study. With regard to the juvenile sample, all participants were seen individually and were read a statement informing them of anonymity and their right to withdraw from the research. Juvenile names and numbers were not recorded but a participant number was issued. The list was then destroyed as soon as the testing was completed. Ethical approval for the research was gained through the Human Research Ethics Committee at the University of Hong Kong.

### 2.3. Measures

#### 2.3.1. General intellectual ability

General intellectual ability of the participants was estimated by the oral vocabulary subtest of the HK-WISC (Psychological Corporation, 1981). The correlation of this subtest with the domain of verbal intelligence in the HK-WISC was 0.71. The participants' vocabulary knowledge was used as a proxy to measure general verbal ability as in previous studies (e.g., McBride-Chang & Ho, 2005; McBride-Chang & Kail, 2002). The oral vocabulary subtest included thirty-two items. Participants were given the target words and required to explain the concepts of these words orally. The test was terminated if the participant scored 0 on five questions in a row. Participants with scaled score 7 or above (mean score = 10, 1 SD = 3) were included in the study. The inclusion criteria were to exclude those who might have poor EF merely because of poor intellectual abilities.

#### 2.3.2. Measures for classification of RD

Two sets of cognitive subtests and two sets of literacy subtests from the Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Junior Secondary School Students (HKT-JS) were administered (Chung et al., 2007). Participants who obtained an average scaled score 7 or below (mean scaled score = 10, 1 SD = 3) on both cognitive and literacy subtests were included in the two groups with dyslexia (RD only or AS + RD).

#### 2.3.3. Measures for classification of AS

The TRF Attention Problems scales (Achenbach, 1991) were used for classification of AS. To give a general overview, TRF assesses eight syndromes: Withdrawn, Somatic Complaints, Anxious/Depressed, Social Problems, Thought Problems, Attention Problems, Delinquent Behaviour, and Aggressive Behaviour. Additionally, the first three syndromes combine to form a broadband Internalizing Disorder and the last two form a broadband Externalizing Disorder. Finally, there is a Total Problems score for the whole questionnaire (Achenbach, 1991). The Attention Problems scale consisted of twenty questions with half on inattention symptoms and half on hyperactivity-impulsivity symptoms. Teachers were required to respond to each item using a 3-point Likert scale (Achenbach, 1991).

To explore the criterion validity in the Chinese population, Leung et al. (2006) examined the psychometric properties of the Chinese version of TRF using an extensive Hong Kong community and clinical samples. He suggested that a borderline case was defined by T-scores of 67 or more with a sensitivity of 32% and specificity of 95%. On the other hand, a clinical case was defined by T-score of 70 or more with a sensitivity of 45% and specificity of 95%. Overall, the Attention Problems scales yields large area under the curve (0.91) in terms of criterion validity, and is concluded as valid in identifying children with inattention or hyperactive traits (Leung et al., 2006).

Moreover, as suggested by Leung and his colleagues (Leung et al., 2006), borderline cut off is comparatively optimal in raising the sensitivity and reducing the number of false negatives. Hence, participants in the current study were included in the AS groups (AS only or AS + RD) if their subscale scores are higher than the lowest borderline cut off ($t > 67$) in either Inattention subscale or hyperactivity–impulsivity subscale.

*2.3.4. Measures of executive function*

*2.3.4.1. Stroop Colour and Word Test (Stroop, 1935).* The Stroop Colour and Word Test included word condition, colour condition and colour-word condition. Participants were required to name as many of the stimuli as possible within one minute. In the word condition, participants were required to name the Chinese names of colours printed in black ink. On the subsequent colour condition, participants were asked to name the colour of nonlinguistic coloured patches of red, blue and green ink. Finally, in the colour-word condition, participants were asked to name the colour in which an incongruent word in printed (e.g., the word 'red' printed in green colour). The Stroop Colour and Word test is a popular test for testing inhibition (e.g., Ellis, Weiss, & Lochman, 2009). Specifically, researchers have found that the first two conditions are sensitive in measuring naming speed while the last condition is sensitive in measuring the ability to inhibit dominant or automatic responses (i.e. tendency to read a colour name instead of the colour of the ink in which the colour is named) (Dimoska, McDonald, Kelly, Tate, & Johnstone, 2011; Ellis et al., 2009).

*2.3.4.2. Backward digit spans subtest from the Wechsler Intelligence Scale for Children, Third Edition (Psychological Corporation, 1981).* The Backward Digit Span test is a subtest of the WISC-III (Psychological Corporation, 1981). Participants were asked to repeat two to a maximum of eight auditorily presented digits in backward order. Recent researches suggest that in order to recall the auditorily presented digits in backward order, participants need to inhibit the ongoing activity (the originally presented digit sequence), and select relevant versus irrelevant information to maintain in working memory. This scale was reported to be sensitive in measuring verbal working memory and inhibition (e.g., Jacobson et al., 2011).

*2.3.4.3. Benton visual retention test (BVRT) (Sivan, 1992).* BVRT in general is a measure of visual working memory (Sivan, 1992). To briefly overview, it consisted of ten visual designs that required participants to reproduce by drawing. The first two designs consisted of one major geometric figure and the other eight designs consisted of two major figures and a smaller peripheral figure. The test consisted of three forms and four administrations. In the current study, each design was displayed for ten seconds and then withdrawn. Participants were then required to reproduce the design immediately from memory at their own pace on a blank piece of paper. A strength of the BVRT is that it not only provides a global Errors score but also yields scores for different type of errors to facilitate more comprehensive interpretation. One of the most consistent patterns that exhibited clear developmental pattern is found between left and right errors variables, and which are suggested to examine spatial working memory with interfering visual representations (Sivan, 1992), and has been consistently reported sensitive in assessing executive functions under the construct of working memory.

*2.3.4.4. Contingency naming test (CNT) (Taylor et al., 1990).* CNT consists of four rules of increasing difficulty that are applied to a stimulus set of 9 practice items and 27 test items. Each stimulus was composed by an outer shape (i.e. circle, triangle and square) of different colour (blue, yellow and red), and one smaller independent shape (i.e. circle, triangle and square) embedded inside each of the outer shape. And some of the stimuli include a backwards arrow that appears directly above the outer shape. Participants were asked to name the stimuli according to different level of rules under explicitly timed conditions. In level A, participants were required to name the colour (Rule A1) or the shape (Rule A2) of each stimulus. In level B, participants were required to switch between naming the stimuli by colour or by shape, depending on one attribute (Rule B1) or two attributes (Rule B2).

Unlike other existing measures of EF, CNT demands no suppression on automatic response (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Instead, participants have to "choose" which of the two equally salient responses is appropriate (Kirk, Mazzocco, & Kover, 2005). Even though the interpretation of CNT scores varied, there is a general consensus that Level A is a test of naming speed and Level B is a test of interference control which assesses the "ability to consciously ignore or inhibit irrelevant information while executing a plan" (Dempster & Corkill, 1999, p. 397). Processing speed has been regarded as both EF and non-EF measures in different studies. For one reason that tasks particularly rely on executive processes are presumed to impose substantial demands on self-directed strategy formation (Stuss & Benson, 1986), and nonhabitual responses (Phillips, 1997). For the time and efficiency subtests of the contingency naming test (CNT), participants must keep track of their responses efficiency and time and which require efficient organization of retrieval and recall as well as self-monitoring aspects of cognition, and which involves a strategic component.

*2.3.4.5. Tower of London (ToL) (Shallice, 1982).* ToL is a classical neuropsychological task that has been used frequently to measure planning and problem solving in both clinical and nonclinical populations (Banich, 2009; Berg & Byrd, 2002; Berg, Byrd, McNamara, & Case, 2010; Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008; Shallice, 1982; Unterrainer et al., 2004). Participants were presented with a model where three beads were strategically positioned on three rods of descending heights. Participants were then asked to manipulate beads from a predetermined starting position to match the goal position with the predetermined number of moves printed on a separate paper card. In particular, participants were instructed to plan the whole sequence of moves mentally before executing the sequence as their performances were assessed in terms of planning time, solution time, and number of failed attempts. Most researchers use planning time as a separate dependent measure and examine the extent to which other variables impact planning time (i.e., Kaller et al., 2008). Moreover, previous researchers have demonstrated that other parametric properties of the ToL task such as the number of failed attempts also provide important information in the propensity in rule breaking or rule violation during task execution, and suggested the possibility of other executive demand (Berg et al., 2010; Kaller, Unterrainer, Rahm, & Halsband, 2004; Kaller, Rahm, Köstering, & Unterrainer, 2011).

#### *2.3.5. Measure on delinquency outcome*

Delinquency outcomes were measured in terms of severity of delinquency and onset of delinquency. For severity of delinquency, participants indicated that during the previous 12 months they had committed each of the seven crimes never (0), once or twice (1), often (2), or very often (3). The crimes included using a weapon in a fight, breaking and entering, arson, making coercive threats of delinquency, stealing, vandalizing an automobile and physically assaulting someone without provocation. The current measure was developed by Kerr, Tremblay, Pagani, and Vitaro (1997) in an earlier study on the severity of adolescent delinquency. For onset of delinquency, one question asked how old the respondent was when he first committed any of the above crime(s). In sum, the data came from self-report questionnaires. Self-reports are generally accepted as reliable and valid indicators of delinquent behaviour (Hindelang, Hirschi, & Weis, 1981) if conducted under nonthreatening circumstances (Dembo, Williams, Wish, & Schmeidler, 1990). And in order to maximize reliability and validity of the self-report data, questionnaires were administered individually by a trained interviewer, and participants were instructed not to put their names on any questionnaire, and reassured the confidentiality of their responses.

## 3. Results

### *3.1. Descriptive statistics*

Table 1 summarizes the descriptive statistics for each group. Group differences were found in general ability ($F(1,107) = 13.25, p < 0.001, n_p^2 = 0.26$) and education level ($F(1,107) = 5.05, p < 0.001, n_p^2 = 0.12$). No difference was found in age ($F(1,107) = 2.29, p = 0.08, n_p^2 = 0.06$). Post hoc pairwise comparisons revealed that all three study groups had significantly lower scores in general ability than the control group. Among the three disorder groups, the general ability score of the comorbid group was significantly lower than the pure AS group ($p < 0.001$). For education level, the control group had significantly more years of study than the pure RD ($p < 0.001$) and comorbid groups ($p < 0.001$), but only differed marginally significantly than the pure AS ($p = 0.06$). Furthermore, the three study groups did not differ in age of first drop out ($F(1, 65) = 2.18$, $p = 0.12$, $n_p^2 = 0.07$) or family income ($F(1, 107) = 1.52$, $p = 0.21$, $n_p^2 = 0.04$).

### *3.2. Principal component analysis*

A principal component analysis (PCA) was conducted to separate specific EF dimensions. Nineteen scores from the five EF tasks were entered into the analysis (Table 2). The factors extracted by the Varimax rotation method with Kaiser normalization were used to compute factor scores. The Varimax rotation using factor scores resulted in orthogonal factors which did not correlate with each other with inter-factor correlations $rs = 0.00$. Given the nature of the tests, factor loadings

**Table 1**
Characteristics of control and delinquents with RD, AS and AS + RD.

| | Control ($N = 29$) | (1) | RD-only ($N = 24$) | (2) | AS-only ($N = 29$) | (3) | AS + RD ($N = 35$) | (4) | $F$ | $P$ | $\eta_p^2$ | Post hoc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age | 14.52 | (0.80) | 15.15 | (1.21) | 14.93 | (1.03) | 15.11 | (1.06) | 2.29 | 0.08 | 0.06 | |
| General ability[a,b] | 13.24 | (3.23) | 9.70 | (2.24) | 11.07 | (3.59) | 8.86 | (2.28) | 13.25 | 0.00** | 0.26 | $1 > 2$; $1 > 3 > 4$ |
| Education level[c] | 8.69 | (0.81) | 7.83 | (0.82) | 8.24 | (1.01) | 7.97 | (0.86) | 5.05 | 0.00** | 0.12 | $1 > 2,3,4$ |
| | ($N = 0$) | | ($N = 20$) | | ($N = 22$) | | ($N = 24$) | | | | | |
| Age of first drop-out | – | – | 12.40 | (1.47) | 12.23 | (1.02) | 11.46 | (2.11) | 2.18 | 0.12 | 0.07 | |
| Family income | 5.10 | (2.61) | 5.21 | (3.24) | 4.31 | (2.95) | 5.91 | (3.17) | 1.52 | 0.21 | 0.04 | |
| Severity of delinquency | .34 | (0.81) | 1.55 | (0.34) | 3.81 | (0.53) | 5.73 | (0.17) | 20.21 | 0.00** | 0.38 | $4 > 3 > 1, 2$ |
| Age of onset | – | – | 12.26 | (1.82) | 11.63 | (1.81) | 11.58 | (2.59) | 0.66 | 0.52 | 0.02 | |

[a] Vocabulary subtest of Wechsler Intelligence Scale for Children, Third Edition (Psychological Corporation, 1981).
[b] Scaled score.
[c] American Grade System.
** $p < 0.01$.

**Table 2**
Principal component analysis of executive functions.

| Measure | Component 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| CNT-Total Efficiency | **−0.826** | −0.146 | −0.017 | 0.112 | −0.007 | −0.238 |
| CNT-Total Time | **0.814** | 0.410 | 0.269 | −0.015 | 0.047 | −0.038 |
| CNT-Efficiency (Level B2) | **−0.804** | −0.021 | −0.120 | 0.012 | 0.035 | −0.275 |
| CNT-Time (Level B1) | **0.802** | 0.268 | 0.176 | −0.127 | 0.061 | −0.088 |
| CNT-Time (Level B2) | **0.788** | 0.145 | 0.357 | 0.032 | −0.004 | −0.006 |
| CNT-Efficiency (Level B1) | **−0.784** | −0.075 | −0.091 | 0.245 | −0.086 | 0.024 |
| CNT-Time (Level A1) | 0.159 | **0.883** | −0.032 | 0.064 | −0.010 | −0.059 |
| CNT-Efficiency (Level A1) | −0.119 | **−0.876** | 0.001 | −0.021 | 0.053 | 0.027 |
| CNT-Time (Level A2) | 0.170 | **0.854** | 0.012 | 0.002 | 0.184 | 0.034 |
| CNT-Efficiency (Level A2) | −0.161 | **−0.852** | −0.081 | 0.011 | −0.131 | −0.018 |
| Stroop Colour-Word Processing | −0.123 | **−0.692** | −0.280 | 0.155 | 0.279 | −0.072 |
| Benton-Total Error | 0.255 | 0.072 | **0.937** | −0.005 | −0.020 | 0.056 |
| Benton-Error (Right side) | 0.276 | −0.020 | **0.816** | 0.076 | −0.125 | 0.056 |
| Benton-Error (Light side) | 0.103 | 0.138 | **0.780** | −0.127 | 0.120 | 0.088 |
| Tower of London-Trail score | −0.176 | −0.026 | −0.014 | **0.898** | 0.115 | 0.186 |
| Tower of London-No of Attempt | −0.144 | 0.029 | −0.078 | **0.853** | 0.021 | −0.360 |
| Backward Digit Span | 0.057 | 0.057 | −0.062 | 0.161 | **0.854** | 0.066 |
| Stroop-Interference | −0.061 | 0.009 | −0.476 | 0.109 | **−0.502** | 0.083 |
| Tower of London-Planning Time | 0.176 | −0.002 | 0.116 | −0.061 | 0.028 | **0.910** |

*Note*: Bold numbers in a column indicate most prominent loadings to a corresponding factor. CNT, contingency naming test; Benton, Benton visual retention test.

could be assigned as follows: Factor 1, interference control; Factor 2, processing speed; Factor 3, visual memory; Factor 4, problem solving; Factor 5, inhibition; and Factor 6, planning.

To determine whether the pure disorders were significantly associated with poor performance on any of the EF measures, a series of 2 (RD vs. no RD) × 2 (AS vs. no AS) between-subjects analyses of covariance (ANCOVAs) were conducted. Participants' general ability scores were entered as a covariate. Planned comparisons using independent sample *t*-tests were conducted to test the three comorbidity hypotheses (see Table 3 for results).

### 3.2.1. Executive function

*3.2.1.1. Interference control.* No significant main effect was found on either RD ($F(1,103) = 2.29$, $p = 0.13$, $n_p^2 = 0.02$) or AS ($F(1,103) = 2.17$, $p = 0.14$, $n_p^2 = 0.02$) suggesting that the presence of RD or AS has no effect over the performance of interference control. However, there was a significant interaction effect between AS and RD, $F(1,103) = 6.06$, $p = 0.02$, $n_p^2 = 0.06$. Post hoc analysis showed that the performance of the comorbid group was significantly worse than the pure RD ($p = 0.01$), pure AS group ($p < 0.01$) and control group ($p = 0.01$). This pattern of results implied that the comorbid condition led to a serious impairment in interference control while the single condition alone did not.

*3.2.1.2. Processing speed.* The processing speed factor consisted of measures from CNT and the Stroop test measuring the speed of name retrieval. The main effect of RD was significant, $F(1,103) = 11.04$, $p = 0.01$, $n_p^2 = 0.10$. Neither the main effect of AS nor the interaction between AS and RD was significant (main effect of AS, $F(1,103) = 0.25$, $p = 0.62$, $n_p^2 = 0.00$, interaction effect between the two IVs, $F(1,103) = 0.00$, $p = 0.97$, $n_p^2 = 0.00$. Results showed that there were significant group differences ($p = 0.01$) among the four groups. In details, the control group performed significantly better than the pure RD group ($p = 0.02$) and comorbid group ($p = 0.01$) but not the pure AS group ($p = 0.71$). Moreover, the pure AS group performed significantly better than the pure RD ($p = 0.04$) and comorbid group ($p = 0.01$).

**Table 3**
Means and standard deviations for the measures of executive function for each of the study groups; main effects and interactions from the 2 × 2 analysis of covariance (ANCOVA) are also displayed.

| | Control (1) ($n = 25$) | | Pure RD (2) ($n = 22$) | | Pure AS (3) ($n = 27$) | | AS + RD (4) ($n = 34$) | | Main effect | | | | Interaction | | | ANCOVA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | RD | | AS | | RD X AS | | | |
| Executive Function | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *F* | $n_p^2$ | *F* | $n_p^2$ | *F* | $n_p^2$ | *F* | Post hoc |
| Interference Control | −0.16 | 0.77 | −0.24 | 0.81 | −0.30 | 0.89 | 0.51 | 1.17 | 2.29 | 0.02 | 2.17 | 0.02 | 6.06* | 0.06 | 4.08** | 1, 2, 3 > 4 |
| Processing Speed | −0.38 | 0.79 | 0.27 | 1.15 | −0.31 | 0.83 | 0.35 | 1.02 | 11.04** | 0.10 | 0.25 | 0.00 | 0.00 | 0.00 | 3.83* | 1, 3 > 2, 4 |
| Visual Memory | −0.70 | 0.60 | 0.32 | 0.74 | −0.06 | 0.84 | 0.36 | 1.23 | 10.58** | 0.09 | 2.72 | 0.03 | 2.42 | 0.02 | 4.62** | 1 > 2, 3, 4 |
| Problem Solving | 0.14 | 0.90 | −0.63 | 1.21 | 0.01 | 0.91 | 0.29 | 0.83 | 1.72 | 0.02 | 3.92* | 0.04 | 7.89** | 0.07 | 4.39** | 1, 3, 4 > 2 |
| Inhibition | −0.73 | 10.07 | 0.15 | 0.84 | 0.49 | 0.91 | 0.04 | 0.84 | 1.94 | 0.02 | 10.07** | 0.09 | 14.23** | 0.12 | 7.91** | 1 > 2, 3, 4 |
| Planning | −0.59 | 1.26 | 0.40 | 0.52 | 0.14 | 0.80 | 0.06 | 1.00 | 4.17* | 0.04 | 0.87 | 0.01 | 7.88** | 0.07 | 3.66* | 1 > 2, 3, 4 |

* $p < 0.05$.
** $p < 0.01$.

*3.2.1.3. Visual memory.* The visual memory factor consisted of scores (total number of error, left-side error, right-side error) from the BVRT, which measured the adequacy of visual memory. Similar to processing speed, only the main effect of RD on visual memory was significant, $F(1,103) = 10.58$, $p = 0.00$, $n_p^2 = 0.09$, showing that participants with RD performed worse in visual memory than those without. Pairwise comparison showed that there was a significant group difference among all groups ($P = 0.01$) with the control group performing significantly better than the other three disorder groups. However, no significant difference was found between the three disorder groups.

*3.2.1.4. Problem solving.* The problem solving factor was comprised of the total score and attempt score from ToL, which measured the cognitive process in adopting effective strategies for achieving goals (Kaller et al., 2008). There was a significant main effect of AS on problem solving, $F(1,103) = 3.92$, $p = 0.05$, $n_p^2 = 0.04$ but not the RD group, $F(1,103) = 1.72$, $p = 0.19$, $n_p^2 = 0.02$. Participants with AS performed better than non-AS in problem-solving skills. There was a significant interaction effect between the two group factors, $F(1,103) = 7.89$, $p = 0.01$, $n_p^2 = 0.07$. The interaction effect revealed that having a positive AS status might improve the performance in the problem-solving domain, leaving the pure RD group as the only group with poor performance. Subsequent post hoc analysis revealed that the pure RD group performed significantly worse than the other three groups: Control ($p = 0.01$), pure AS ($p = 0.02$) and Comorbid ($p = 0.01$). However, no significant differences were found between the other three groups.

*3.2.1.5. Inhibition.* The inhibition factor comprised two variables: backward digit span and Stroop-interference score, which measured the suppression of irrelevant information from working memory. There was a significant main effect of S on Inhibition, $F(1,103) = 10.07$, $p = 0.00$, $n_p^2 = 0.09$. The main effect of RD was not significant, $F(1,103) = 1.94$, $p = 0.17$, $n_p^2 = 0.02$. There was also a significant interaction effect between the two factors $F(1,103) = 14.24$, $p = 0.00$, $n_p^2 = 0.12$. It suggested that the performance in inhibition was mainly impaired by the presence of AS. Nevertheless, the presence of RD moderated such an effect so that with the presence of RD, AS status did not affect participants' performance in inhibition. The results of the post hoc analysis indicated that control group performed significantly better than the other three study groups, all $p < 0.001$ and the comorbid group performed similarly to the pure groups.

*3.2.1.6. Planning.* The planning score from the ToL was the only score in this factor which measured the time participants spent on modelling and anticipating the consequences of action before attempting to execute the goals (Kaller et al., 2008; Unterrainer & Owen, 2006). There was a significant main effect in the RD group ($F(1,103) = 4.17$, $p = 0.04$, $n_p^2 = 0.04$) in that participants with RD used significantly less time planning than subjects without RD in this domain. No main effect in the AS group was found, $F(1,103) = 0.87$, $p = 0.35$, $n_p^2 = 0.01$. There was a significant interaction effect between the two group factors, $F(1,103) = 7.88$, $p = 0.01$, $n_p^2 = 0.07$. It suggested that with the absence of AS, RD alone incurred significant impairment to the performance in planning. However, when the AS status was presence, the effect of RD in planning was minimized, such that a positive AS status actually reduced the impairment in planning. Post hoc analysis revealed that the control group used significantly more time than the other three disorder groups in planning. Yet again, the comorbid group performed similarly to the pure groups.

### 3.3. Predicting delinquency outcome

To determine the impact of comorbidity on delinquent behaviour, self-reported delinquency scores and age of onset were compared separately between the four groups using analysis of covariance (ANCOVA) with group as the independent variable and self-reported delinquency scores on severity or age of onset as the dependent variable, and general ability scores as covariance (see Table 1). Results revealed that the comorbid group had significantly higher scores in severity of delinquency than the other three groups (all $ps < 0.01$). Furthermore, the pure AS group had significantly higher scores than controls ($p < 0.01$) and the pure RD group ($p < 0.01$). There was no significant difference between the control and pure RD groups ($p = 0.32$). For the onset of delinquency, since only 3 out of 29 participants in the control group reported commitment of crime, only the onset of delinquency of the three study groups was compared. Results revealed no between-group differences were found among the three groups, $F(1,103) = 0.67$, $p = 0.51$, $n_p^2 = 0.02$.

A hierarchical regression analysis that controlled for general intellectual ability was conducted to examine which EF factors best predicted the two delinquency outcomes. Table 4 shows that EF accounted for an additional 12.8% of the variance in severity of delinquency over general ability, and interference control was the only significant predictor of severity of delinquency after controlling for general ability. Moreover, it is worthy of note that inhibition ($\beta = 0.16$, $t = 1.89$, $p = 0.06$) was found to marginally predict the severity of delinquency. None of the EF predictors predicted the onset of delinquency.

## 4. Discussion

### 4.1. EF of individuals with AS and RD

The present findings suggested that AS and RD were associated with distinct weaknesses on different measures of EF. Consistent with our hypothesis and findings of past research studies, the present findings showed that AS was associated with a significant weakness on inhibition (e.g., Barkley, 1997; Nigg, 2000, 2001; Schachar, Mota, Logan, Tannock, & Klim, 2000), while RD was associated with deficit on processing speed and visual memory. Such findings also replicated previous

**Table 4**
Hierarchical regressions predicting subjects' self-reported severity scores and age of onset of delinquency from executive functions.

| Step | Variables | Severity scores | | | | Age of onset | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total $R^2$ | $R^2$ change | Standardized beta | $t$ | Total $R^2$ | $R^2$ change | Standardized beta | $t$ |
| 1 | IQ | 0.135 | 0.135 | 0.067 | −4.062** | 0.019 | 0.019 | 0.136 | 1.07 |
| 2 | IQ | 0.263 | 0.128 | −0.248 | −2.674** | 0.057 | 0.039 | 0.089 | 0.630 |
| | Interference control | | | 0.222 | 2.549* | | | −0.158 | −1.108 |
| | Processing speed | | | 0.153 | 1.768 | | | 0.099 | 0.701 |
| | Visual memory | | | 0.136 | 1.526 | | | 0.025 | 0.183 |
| | Problem solving | | | 0.129 | 1.506 | | | −0.017 | −0.126 |
| | Inhibition | | | 0.163 | 1.893 | | | −0.022 | −0.153 |
| | Planning | | | 0.089 | 1.016 | | | −0.133 | −0.961 |

* $p < 0.05$.
** $p < 0.01$.

studies that naming speed (McBride-Chang & Ho, 2000) and visuospatial memory (Ho & Bryant, 1997) were identified as the significant markers in Chinese dyslexic children. More importantly, participants with comorbidity AS + RD in the present study performed poorly on all EF measures associated with AS (inhibition) and RD (processing speed and visual memory). Moreover, they exhibited a unique deficit in interference control. In other words, the adolescents with either RD or AS alone did not have impairment in interference control but those with the comorbid condition were impaired.

The current study evaluated three different explanations concerning the comorbidity of AS + RD. Since participants in the comorbid condition performed poorly on EF measures related to inhibition as well as linguistic components important for reading Chinese (processing speed and visual memory), the current findings refuted the phenocopy hypothesis (Pennington, Groisser, & Welsh, 1993). Moreover, it also failed to provide support for the idea of shared aetiology (Willcutt et al., 2001, 2005) as significant interaction effects were found on interference control, problem solving, inhibition, and planning. In other words, the comorbid group in the current study did not simply reflect an additive or combined effects of the underlying cognitive deficits from the pure conditions. Finally, the comorbid group demonstrated an additional deficit on interference control that was not shared by the pure conditions alone, and also showed a marginally better performance on problem solving than the pure RD group. The present findings provided further support to the cognitive subtype hypothesis and suggested that the comorbid condition might reflect different causal mechanisms from those operating in either condition alone (de Jong et al., 2006; Rucklidge & Tannock, 2002). It implies that the comorbidity AS + RD could be a separate or subtype of the disorder that is caused by aetiological factors that are partially distinct from those that underlie AS and RD separately (e.g., Bental & Tirosh, 2007; Rucklidge & Tannock, 2002). Nevertheless, to the best of our knowledge, this is the first study to identify interference control as the additional EF deficit in the comorbid condition (e.g. Sarkis, Sarkis, Marshall, & Archer, 2005), and there is no research so far explain any possible mechanism on the relationships between the cumulative effect of the EF deficit from the pure groups to the manifested EF deficits in the comorbid condition. Future research examine such mechanism would have high theoretical and implicational significance in understanding the impact of comorbidity to delinquency.

#### *4.1.1. Skills measured by the tower of London task*

There are some unexpected findings related to the ToL task. Groups with AS showed a better performance in problem solving and this was not found in past studies (e.g., Riccio, 2004). This may be explained by the fact that the current version of ToL also involves other skills like motor output (Phillips, 1997). Adolescents with AS might have improved their performance through better motor response coordination and timing of output, which should be considered as an impulsive "trial and error" strategy rather than a true problem solving ability (Brosnam et al., 2002; Oosterlaan, Scheres, & Sergeant, 2005; Reiter, Tucha, & Lang, 2005). In addition, the current study revealed that RD instead of AS was associated with the negative main effect in planning, suggesting that RD condition was associated with significantly shorter planning time before task execution. In fact, ToL includes specific rules that must be adhered to in the execution of the solution (Riccio, Sullivan, & French, 2002). The planning component of ToL lies in the presumption that the individual will plan the course of action or visualize the steps in advance with the use of rules (Levin et al., 1994). Therefore, the short planning time in a group of RD may be the results of their poor rule-learning ability as consistently demonstrated in past literature (e.g., Nicolson, Fawcett, Brookes, & Needle, 2010), and which result in an impulsive pattern of task execution. Further studies should include a more comprehensive version of the ToL task such as TOL–Drexel Version (TOLDX; Culbertson, Zillmer, & Di Pinto 1999). This version simplified the instructions by using a second tower to display the desired goal and demonstrated rules involved. Moreover, it also adds more difficult items so that the "trial and error" effect can be minimized (Riccio, Wolfe, Romine, Davis, & Sullivan, 2004).

### 4.2. Comorbidity and delinquency

Our second objective was to determine the impact of comorbidity of RD and AS on delinquency. Despite there being no between-group difference found on age of onset, the present findings showed that the comorbid group was associated with a higher score in severity of delinquency than the other three groups and this was consistent with my expectation. Moreover, interference control, the unique deficit exhibited in the comorbid group, was found to be the only significant predictor of severity of delinquency. In fact, some studies have reported the association between poor interference control and aggressive behaviour (e.g., Ciairano, Visu-Petra, & Settanni, 2007). In particular, the study conducted by Ciairano et al. (2007) suggested that poor interference control would result in aggression through deficiency in choosing an appropriate behaviour in challenging social situations (Greenberg, Kusche, & Riggs, 2004). They explained that while some children may pay attention to multiple aspects of social cues, children with poor interference control may show high vigilance to perceived threats, encrypting fewer interpersonal cues before interpreting the intentions of their peers, which results in a high level of aggression (Greenberg et al., 2004).

## 5. Limitations and future directions

Despite general agreement of the current findings with similar studies, there were a number of methodological limitations which need to be considered. First, despite the fact that the present study tried to screen all the delinquent boys in the juvenile institutions in Hong Kong, the sample size was relatively small with around 30 adolescent males in each group. Second, due to the time constraint and diagnostic limitation such as low parental involvements, ADHD symptoms instead of full structured diagnostic ADHD was examined, and only a specific set of cognitive and literacy subtests were administered. Even though these subtests are proven to be sensitive in screening the two disorders, future study may include standardized diagnostic assessment for ADHD, RD subtypes, and comorbidity conditions. Third, there has long been recognition that delinquent behaviour does not constitute a homogeneous entity, but a considerable versatility (Hindelang et al., 1981). Future study may provide a standardized measure on delinquency outcomes so that meaningful comparison can be adequately made. Moreover, the fourth limitation in the current thesis was that it only made clear that specific neuropsychological risks factors were able to predict certain type of delinquency outcomes. However, this study could not yield any causal relationships and it is not clear how these risk factors exert their influence to those particular delinquency outcomes. Future studies should therefore adopt a longitudinal approach that would provide valuable information about the relationships between life-span development and criminal career in each group of adolescents. The current thesis suggested that EFs such as interference control and inhibition are highly predictive to the severity of delinquency. Hence, it might be possible that addressing the issue of EF might protect the at-risk adolescents from committing delinquent acts. Moreover, it also provided preliminary evidence that comorbidity of AS and RD might affect delinquency severity. It is therefore sensible to wonder if adolescents in the comorbid condition have a higher chance of engaging in a severe pattern of offending. An answer to this question would have high theoretical and practical significance. Hopefully, the current findings will provide a more comprehensive picture of the unique EF deficits associated with different groups, allowing for better matching for future identification and intervention programme.

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