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Motor control and sequencing of boys with Attention-Deficit/Hyperactivity Disorder (ADHD) during computer game play

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Abstract

The motor control of 49 unmedicated boys clinically diagnosed with ADHD, case-matched with 49 non-ADHD boys, was assessed while playing Crash Bandicoot I, a Sony™ Playstation platform computer video game. In Crash Bandicoot participants control the movements of a small-animated figure through a hazardous jungle environment. Operationally defined measures of motor control were designated by (1) the stage of the game completed (ie, the number of obstacles successfully passed) before losing the figure's 'life', (2) the level of complexity that the stage represented and (3) the time taken to get to that point during the video game play. These measures were assessed under contrasting conditions of low or high working memory and distracter loads. Four tasks were administered (totalling 12 trials), incorporating both with and without distracter conditions. For those trials with the distracter, a segment of the television show *The Simpsons* was simultaneously played on a television screen adjacent to the computer game monitor. A 5-way MANOVA revealed that ADHD boys took less time to complete their trials under the direct condition (ie, no working memory load) on Crash Bandicoot, compared to their matched non-ADHD peers. When the task required additional working memory, however, the ADHD boys took significantly longer. Cumulative frequency plots of game performance revealed that in terms of the number of obstacles completed, the control participants successfully navigated more obstacles on the low working memory load task than the ADHD participants, but that the performance of the two groups was less distinguishable on the high working memory load task. The findings have implications for assessment and management of children with ADHD.

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Attention-Deficit/Hyperactivity Disorder (ADHD) (DSM-IV TR, American Psychiatric Association, 2000) is the current diagnostic label for one of the most prevalent neurodevelopmental disorders of childhood. ADHD is recognised to be comprised of difficulties with sustained attention, distractibility, impulse control and hyperactivity (Barkley, 1997; Houghton *et al*, 1999; Schachar *et al*, 2000). Although most individuals with ADHD have symptoms of both hyperactivity/impulsivity and inattention, there are some individuals in whom one or the other pattern is predominant. Thus, the subtypes of ADHD are *ADHD Predominantly Hyperactive-Impulsive Type* (ADHD-HI); *ADHD Predominantly Inattentive Type* (ADHD-PI); and *ADHD Combined Type* (ADHD-CT) (see DSM-IV TR, American Psychiatric Association, 2000).

A recent theoretical model (Barkley, 1997) of ADHD posits that the essential impairment in ADHD is one of behavioural inhibition, and that this leads to secondary impairments in four other executive functions (ie, functions which involve inhibiting, initiating, planning, hypothesis generation, cognitive flexibility, decision making, regulation, judgement, feedback utilisation, sequencing of actions and resistance to interference (Denckla, 1996), namely: operation of working memory; internalisation of self-directed speech; controlling mood, motivation and arousal; and reconstitution (or the ability to break down and recombine sequences of behaviour into novel responses). Barkley's theory has received extensive support in the scientific literature from studies using standardised assessment procedures which demonstrate that children with ADHD experience impairments in their executive functioning (see Houghton *et al*, 1999; West *et al*, in press). These executive functions are mediated by the frontal lobes of the brain, which are primarily dedicated to the control of motor behaviour, with prefrontal areas providing the cognitive support necessary for the behavioural output (see Rubia *et al*, 1999). The successful execution of executive functions thus allows for motor control, complex sequencing and goal-directed behaviour essential for effective self-regulation (Barkley, 2001a, b).

In children with ADHD this is not the case, and on computerised laboratory-based tasks motor control has been shown to be clearly impaired (Schachar *et al*, 2000). Specifically, ADHD and hyperactive children have been found to respond more rapidly, more prematurely and more inaccurately than controls (see Rubia, Taylor and Sergeant, 1999 for a review). When speed in responding has been necessary ADHD and hyperactive children have also been less able to adjust their speed of responding (Carte, Nigg and Hinshaw, 1997). Conversely, when allowed to choose their own speed on a computerised motor task these individuals have not only been found to be relatively and inappropriately fast, but have also demonstrated highly inconsistent rhythm production, sensorimotor synchronisation and anticipation, suggesting that they have dysfunctional temporal control of their motor output (Rubia, Taylor and Sergeant, 1999).

According to Lezak (1995), however, computerised continuous performance tasks may not elicit optimal cognitive performance, and as a result the findings to date may reflect

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motivational issues rather than executive function deficits. This assertion was examined in a recent unique study (Lawrence *et al*, 2002) which used a computer video adventure game. Among the unexpected findings was that some of the executive functions as operationalised in Barkley's model were clearly not dysfunctional. Contrary to Barkley's theory no significant differences between individually matched (on age, IQ and computer game familiarity) boys with and without ADHD were evident on some aspects of behavioural inhibition, non-verbal working memory and reconstitution. Furthermore, the ADHD boys were significantly more proficient in some aspects of reconstitution than their non-ADHD peers. Deficits were clearly evident, however, in motor control.

Computer games thus provide a valuable, ecologically valid, small-scale environment known to be highly motivating to children with ADHD, and in this respect motor tasks within computer games provide a more valid environment than routine laboratory-type tasks in which to test children with ADHD. Furthermore, video game tasks appear to promote optimal cognitive performance (relative to experimental tests) in children with ADHD by providing external motivating contingencies just prior to and at the moment of responding. Tasks administered in this medium also seem to heighten the activation/arousal state of boys with ADHD, and this may also promote their optimal performance (Koepp *et al*, 1998; Kuntsi, Oosterlaan and Stevenson, 2001). Some games entail challenging motor demands, such as the dynamic representation of space, planning, anticipation of temporal events and avoidance of distracters which provide opportunities for genuine interactions (Donchin, 1995; Greenfield, 1994; Okagaki and Frensch, 1994). Therefore, the present research sought to determine the extent to which the motor control difficulties identified in the performance of boys with ADHD on standardised computer laboratory–based tasks generalised to the 'micro' environment of computer video game play.

Method

Participants

An initial total sample of 146 boys aged between 6 years 3 months and 16 years 1 month participated in the study ($M = 9.6$ years, $SD = 2.1$). Of these 79 were diagnosed as ADHD (30 were diagnosed as ADHD Predominantly Inattentive Type [ADHD-PI] and 49 were diagnosed as ADHD Combined Type [ADHD-CT]). The remaining 67 participants were the control group of non-ADHD boys who were recruited from a local public primary school. The ADHD participants were primarily recruited through one consultant paediatrician with a clinical practice serving a large urban population in Perth, Western Australia. The school from which control boys were recruited was situated within the same socio-economic region of the city as that of the paediatrician's practice. The minimum requirement for participation in the study was a Verbal or Performance IQ score of at least 80 points based on estimates obtained using four subtests (ie, Vocabulary, Similarities, Block Design and Object Assembly) of the *Wechsler Intelligence Scale for Children*, 3rd Edition (WISC-III, Weschler, 1991). These subtests correlate .93 to .95 with the full administration of the WISC-R (Groth-Marnat, 1990). All participants had normal or corrected vision and none had hearing impairments.

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Children comprising the ADHD group had all been diagnosed by the consultant paediatrician as meeting the DSM-IV (American Psychiatric Association, 1994) criteria for ADHD on the basis of a clinical interview and had subsequently been referred to a clinical psychologist (by the paediatrician) for the assessment of undiagnosed comorbid disorders. To be included in the study they could not have received any additional diagnoses at that time (eg, learning disorders, conduct disorder, anxiety disorder), as indicated in the paediatric and psychological examinations. To reduce the potential for masking effects, all of the ADHD boys had received no stimulant medication for a minimum of 20 hours prior to testing. In a similar manner only those boys who did not have any diagnosed conditions, according to the school psychological assessment and academic records, were included in the control group. The absence of any learning difficulty and/or other conditions in the control sample was confirmed by the principal of the school in consultation with the school psychologist.

Matching procedures

In consideration of anticipated effects of age and motor/visuo-spatial abilities on performance, the boys with ADHD were case-matched for age (within six months) and Performance IQ (within one standard deviation, that is within 15 scaled score points) with a participant from the control group. By individually matching participants there is a decrease in the error variance and this prevents the matching variables from becoming competing causal factors of any effect (Kirk, 1995). In addition, matching induces a correlation between the measures taken on the ADHD and control groups (Kirk, 1995) that facilitates the use of a repeated-measures (ie, correlated samples) design.

Obtaining satisfactory matches for age and IQ, however, necessarily results in a reduction of the available sample. Specifically, data were excluded for 18 boys in the ADHD group for whom there were no appropriately aged controls and for an additional 4 boys with ADHD and 4 control boys for whom there was no appropriate match for age and IQ. Due to human error at the time of recording data, a further two participants were excluded from the final analysis. Therefore, the data reported here were derived from 49 boys with ADHD case-matched with 49 non-ADHD boys from the control group. The ADHD group comprised 17 boys classified as Predominantly Inattentive and 32 classified as Combined Type.

Prior to testing, information was obtained to ascertain the extent of each participant's familiarity with video game play. Video game answers were on a yes/no basis, and the participants were quantified into three categories of novice, average and skilled players. The video categories were determined by answers to the following enquiries: (a) extent of the player's prior experience with the video game, (b) extent of the player's prior experience with the Sony controls used in the study, (c) having a computer at home and (d) frequency of play on an average weekly basis. Data revealed 29 novice players (16 ADHD, 13 controls), 45 average players (22 ADHD, 23 controls), and 24 skilled players (11 ADHD, 13 controls).

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Settings

All of the boys in the ADHD group were tested in a room located in the Centre for Attention and Related Disorders, The Graduate School of Education, The University of Western Australia. Boys in the control group were tested at their school, in a room designated for the study. In both instances, the room was quiet, well lit, well ventilated and free of extraneous distracters. The layout of equipment and furniture was comparable. At both locations the equipment was set up identically. There were two televisions positioned directly in front of the participant. One television served as the monitor for the computer video game play, while the other was used to concurrently show excerpts from an episode of the television show *The Simpsons* (Carey, 1997, 20th Century Fox) during computer video game trials which incorporated a distracter.

Computer video game methods and measures

The video game chosen was a platform game (Crash Bandicoot I, Naughty Dog Software, 1996) which required executive functioning abilities as well as visuo-spatial and eye-hand coordination skills. The game was played on a Sony Playstation™ using a Sony™ hand-held control panel, with left-hand and right-hand keypads. The keypad on the left of the control contained four response buttons arranged in a cross formation; this controlled the directional movement of the video game character (indicated on each button—forward, backward, left and right). The right keypad contained a further four response buttons, only two of which were used in the present study to control two types of vertical action of the character (*spin*, indicated by a circle on the button, and *jump*, indicated by an X on the button). The response buttons on each keypad were spaced approximately 2 cm apart and could be easily activated by the thumb of each hand. By depressing the button the character's movement was immediately initiated; that action continued until the button was released and this immediately stopped the action.

Crash Bandicoot requires the participant to use the response buttons on the hand-held console to control the movements of a small, animated figure, *Crash Bandicoot* (CB), to negotiate successfully through various hazards. These hazards occur while moving along a jungle path in order to reach a designated checkpoint. The game graphics are designed to give the participant the impression that they are standing behind CB and thus can readily assume the character's role, seeing the jungle path and its challenges through CB's eyes. The journey is hazardous and involves risks like falling into chasms or being prevented from progressing along the path by rolling wheels, skunks and snapping plants. The game provides situations in which success/survival depends on being able to alternate rapidly between moving fast towards the designated checkpoint and inhibiting movement to avoid the various hazards, while keeping in mind specific game rules.

Procedure

Consent was given by the Human Rights and Ethics Committee of The University of Western Australia and the consultant paediatrician. Appointment times for the testing sessions were arranged by telephone. During the telephone conversation, parents were

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reminded of the section in the information letter requesting that no stimulant medication be administered to their children on the afternoon or evening prior to the testing (a minimum of 20 hours free of medication). This was checked again immediately prior to testing. All parents complied with this request so that each child was tested in an unmedicated state. This ensured that there were no drug effects on cognitive and/or motor performance during the video game task.

Participants were required to complete one specific game segment under four randomly ordered experimental conditions (tasks), which varied along two dimensions—working memory load (low, high) and distraction (absent, present). Each experimental condition comprised three attempts (trials), with a total of 12 attempts or 'lives' per participant.

Condition 1 was low working memory load with no added distracter, which required the participant to manoeuvre the character CB as quickly as possible from the designated starting point down the jungle path to a specific checkpoint, without touching any of the boxes that appeared along the path. *Condition 2 was high working memory load with no added distracter* and required participants to manoeuvre CB down the jungle path as quickly as possible to the checkpoint, while remembering a specific game rule (spin boxes marked with an arrow). *Condition 3 required low working memory with the distracter added* and *4 required high working memory with the distracter added.* Conditions 3 and 4 were identical to Conditions 1 and 2, respectively, but with the added distracter of a popular television show, *The Simpsons*, being played (with equal volume and graphics tuning) concurrently on an adjacent television screen. The segment involves Bart and his school friends' training for football under the coaching of Homer's neighbour, Ned, and culminates with their triumphant results.

All boys were tested in the morning and allowed three minutes practise time (five minutes for novices) prior to commencing the experimental conditions. This ensured that participants of all ages were sufficiently able to manoeuvre CB along the route past the fourth challenge (which was required to afford adequate measurement). This is in line with previous research (Blumberg, 1998; Bremner and Andreasen, 1998) which has demonstrated that children as young as six years of age have sufficient psychomotor skills to participate successfully in computer game play. Instructions for each of the four conditions (described above) were given immediately before the participant began that condition. Each boy was videotaped while playing to record any body movements during game play. The results of these analyses were presented in an earlier volume of this journal (see Farrace-Di Zinno *et al*, 2001). Participants' video game play was also downloaded directly onto a videocassette. The adult examiner remained with the child throughout the testing, but stayed out of the line of sight of the participant whilst he was playing. Prior to starting each experimental condition, the examiner held the controls while instructions pertaining to the task were given. Administration of all four game conditions lasted about 20 minutes, after which the participants were allowed to play the game for five minutes with no imposed rules (a reward for participating).

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Data collection

This research required the collection of data on motor control which was designated by (1) the stage of the game completed (ie, the number of obstacles successfully passed) before losing the character's 'life', (2) the level of complexity that the stage represented (ie, complexity rating of 1, 2 or 3) and (3) the time taken to get to that point during the video game play. The level of complexity was based on the difficulty of the sequence of obstacles and hence the motor complexity needed to pass through that sequence of the game. Complexity 1 indicated low level motor complexity required to complete the stage (eg, jump a chasm), 2 indicated moderate complexity required to complete the stage (eg, jump chasm and immediately stop at a rolling wheel), and 3 indicated highly complex motor sequencing required to complete the stage (eg, jump chasm, stop at rolling wheel, pass wheel and immediately stop at chasm on other side or jump over it).

In viewing the recorded video game performance of each participant, the researcher was unaware of who had received a diagnosis of ADHD. For each participant a Game Stage Sheet was developed to record the necessary data. Participants' games were timed from the character's starting position at the beginning of the jungle path, to the stage reached (loss of life occurred or checkpoint reached). The time taken and the stage reached were analysed as separate entities.

Statistical analyses

Data were analysed using a 2 (Subtype: ADHD-PI vs ADHD-CT) × 2 (Group: ADHD vs Control) × 2 (Distract: Off vs On) × 2 (Task: Direct vs Indirect) × 3 (Trial: 1, 2 or 3) Multivariate Analysis of Variance (MANOVA) with repeated measures on the last four factors. The three dependent measures taken were Motor Control, Sequence Complexity (Difficulty) and Time Taken to reach stage. Wilks lambda was used to test the significance of hypotheses in the MANOVA and due to the exploratory nature of the research, and the innovative data arising from it, it was decided to examine all hypotheses at the $\propto = .10$ level. Where appropriate, effect sizes were calculated in the event of significant differences between means. The effect size (ES) is a standardised contrast, providing a measure of the difference between the means in standard deviation units that is independent of sample size.

Results

The 31 hypotheses that were tested by the 5-way MANOVA are shown in an abbreviated MANOVA summary table (Table 1). (The full table is available from the first author on request.) As can be seen in Table 1 there is a significant 4-way interaction ($P = .043$), between Subtype, Group, Distracter and Trial. Despite the statistical significance it would be difficult to justify a valid interpretation of this 4-way interaction involving as it does so many independent variables; furthermore, it should be recalled that a real life setting of a video game is the focus thereby making interpretation even more ambiguous. Therefore, the 4-way interaction is not interpreted here.

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*Table 1: *The probability of the multivariate tests (Wilks lambda) and univariate tests (F ratio)*

Effect	*Multivariate P*	*Univariate P*
Between subjects		
Subtype	.726	
Within subjects		
Group	.072	
Group * Subtype	.972	
Distract	.221	
Distract * Subtype	.552	
Task	**<.001**	**Time = .002**
Task * Subtype	.666	
Trial	.209	
Trial * Subtype	.152	
Group * Distract	.993	
Group * Distract * Subtype	.871	
Group * Task	**.057**	**Time = .010**
Group * Task * Subtype	.188	
Distract * Task	.398	
Distract * Task * Subtype	.659	
Group * Distract * Task	.200	
Group * Distract * Task * Subtype	.810	
Group * Trial	.627	
Group * Trial * Subtype	.069	
Distract * Trial	.561	
Distract * Trial * Subtype	.409	
Group * Distract * Trial	.272	
Group * Distract * Trial * Subtype	**.043**	
Task * Trial	.676	
Task * Trial * Subtype	.392	
Group * Task * Trial	.904	
Group * Task * Trial * Subtype	.113	
Distract * Task * Trial	.680	
Distract * Task * Trial * Subtype	.142	
Group * Distract * Task * Trial	.633	
Group * Distract * Task * Trial * Subtype	.558	

Table 1 does, however, reveal a significant 3-way multivariate interaction between Group, Trial and Subtype [$F(6,42) = 2.139$, $P = .069$]. While this is supported by a significant multivariate main effect for Group [$F(3,45) = 2.494$, $P = .072$], neither the multivariate main effect for Trial or Subtype is significant. Further examination of the Group × Trial × Subtype interaction reveals that it is only supported by a corresponding univariate interaction on Time [$F(2,94) = 2.833$, $P = .064$]. In addition, the effect becomes non-significant when the time taken is averaged over the three trials (ie, the Group × Subtype interaction is not significant).

Table 1 also reveals a significant 2-way multivariate interaction between Group and Task [$F(3,45) = 2.692$, $P = .057$], which is supported by multivariate main effects for

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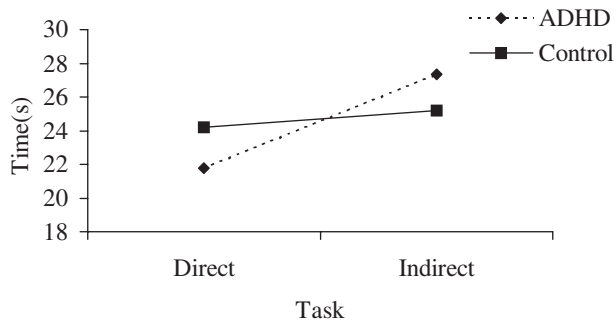

Figure 1: Plot of the Group × Task interaction on Time

both Group [$F(3,45) = 2.494$, $P = .072$] and Task [$F(3,45) = 9.125$, $P < .001$]. The multivariate interaction is supported by a corresponding univariate interaction on Time [$F(1,47) = 7.126$, $P = .010$, $ES = .36$], and the nature of this univariate interaction is illustrated in Figure 1. In particular, it can be seen that while there is little difference in the Time taken by the control group on the direct (ie, not kicking boxes) and indirect tasks (ie, kicking boxes), respectively, there is a significant difference for the ADHD group, who take longer on the indirect task.

The relationship between Group (ie, ADHD vs. control) and Task (ie, Direct vs Indirect) and the number of obstacles completed (ie, Motor Control) was also of interest in the present study. While the Group × Task interaction was not supported by a corresponding univariate interaction, cumulative frequency plots revealed an interesting trend in the number of obstacles completed according to Group and Task. In particular, there is the suggestion that the control participants successfully navigated more obstacles on the Direct Task than the ADHD participants, but that the performance of the two groups is less distinguishable on the Indirect Task. These trends are illustrated using cumulative frequency plots in Figure 2 and Figure 3, respectively.

The significant multivariate main effect for Task [$F(3,45) = 9.125$, $P < .001$] was supported by univariate effects for Time [$F(1,47) = 10.244$, $P = .002$] and Difficulty [$F(1,47) = 3.149$, $P = .082$]. Examination of the means revealed, not surprisingly, that both the ADHD and control participants took longer to reach the corresponding stage of the Indirect Task ($M = 26.25$ seconds) than the Direct Task ($M = 22.99$ seconds). Both groups also reached obstacles with a higher level of difficulty when playing the Direct Task than the Indirect Task. In the absence of a Group factor, however, these results are not considered central to the present study.

The final multivariate main effect for Group [$F(3,45) = 2.494$, $P = .072$] was supported by a univariate effect for Motor Control, suggesting that the mean number of obstacles completed by the Control group ($M = 17.01$) was significantly higher than that for the ADHD group ($M = 14.59$), regardless of Task, Distracter or Subtype.

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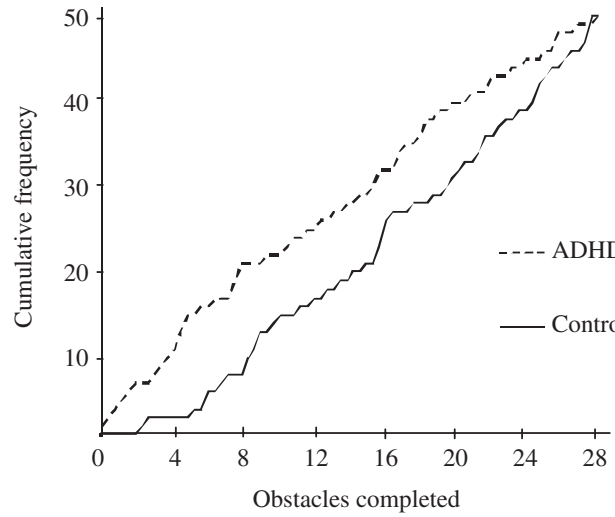

Figure 2: Number of obstacles completed in the Direct Task by Group

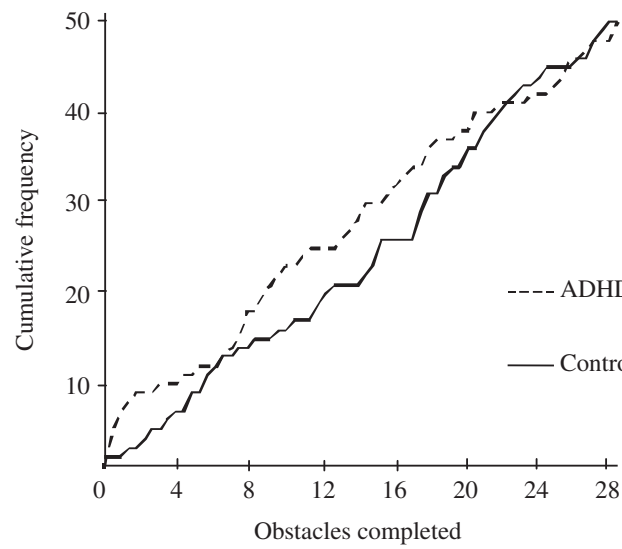

Figure 3: Number of obstacles completed in the Indirect Task by Group

Discussion

The findings of the present research provide some further support for Barkley's (1997) theory, which posits that the inhibitory deficits associated with ADHD lead to secondary impairments in four other neuropsychological abilities, which in turn results in decreased effectiveness in motor control. Some aspects of the findings, however, chal-

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lenge the widely held view of impaired motor control in ADHD children as demonstrated on traditional computerised laboratory tests (Schachar *et al*, 2000; West *et al*, in press).

ADHD boys in this present study took less time to complete their trials under the direct condition (no working memory load and no distracters) on Crash Bandicoot, compared to their matched non-ADHD peers, which is in line with the general clinical perception of these children as individuals who carry out tasks impulsively in the quickest possible time (Tannock, 1998) but in doing so commit more errors (West *et al*, in press). When the number of obstacles completed during game play is examined, however, the boys with ADHD were found to have completed just as many as the non-ADHD boys, which to some extent opposes the clinical perception. While not significant the trends shown in Figure 2 clearly illustrate that more ADHD boys lose their character's life in the early stages of game play and that this continues throughout the duration of play. Conversely, when game play required additional working memory (ie, boys were required to spin open boxes) the performance of the ADHD and non-ADHD boys was less distinguishable, particularly when the complexity in motor sequencing was at its highest (around obstacles 23/24). At this point a convergence in the trends of the ADHD and non-ADHD boys performance occurs (see Figure 3) suggesting that as obstacles become more difficult to successfully negotiate more non-ADHD boys lose their character's life.

Given that motor control was not significantly impaired in the boys with ADHD, it can be speculated that their executive functions (as detailed in Barkley's theory) also may not have been impaired (ie, compared to their matched peers). Given that executive functions are required for motor control and motor fluency, the performance of the boys with ADHD on Crash Bandicoot suggests that in this instance motor control may not be reliant on the successful deployment of executive functions. These findings also offer support, in part, to Lawrence *et al* (2002) who observed that ADHD symptoms were much less apparent when the child is engaged in motivating activities, such as computer video game play.

Although there was no difference in the time taken between the direct task (no kicking boxes) and the indirect task (kicking boxes) for the control group, the ADHD boys took significantly longer when the task required additional working memory (kicking boxes). In this instance participants were required to take the character down the jungle path as quickly as possible whilst avoiding hazards, keeping in mind the added requirement of kicking boxes with arrows marked. This difference in time may therefore be indicative of an underlying working memory deficit, which falls under the model of executive dysfunction proposed by Barkley (1997), and examined by Houghton *et al* (1999) and West *et al* (in press).

Teachers, clinicians and peers involved with children diagnosed as ADHD all draw attention to the disruptive nature of their hyperactive-implusive and inattentive behaviours. The findings of this research suggest that computer technology in the classroom

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may afford children with ADHD increased opportunities to be more successful, both academically and socially, and to improve their interactions with peers. For example, that boys with ADHD can successfully negotiate computer video game demands at levels commensurate with their peers may encourage 'in-school and after-school' friendships. Such friendships will inevitably require appropriate social functioning, an area identified by many (eg, see Brown, 2000 for a review) as problematic for individuals with ADHD. Thus, computer video game play may be beneficial in enhancing social functioning and is therefore worthy of further investigation.

The performance of the boys with ADHD in the present study demonstrates that they can overcome the difficulties in persistence noted in previous research using computer-based continuous performance tasks (see West *et al*, in press). It may be the case that traditional tasks, such as the stop-signal task, the Stroop or continuous performance tasks actually promote less successful performances from children with ADHD. Such laboratory-based tasks are set up to examine scientifically the variable(s) denoting fallibility in the child, and to do so must essentially screen out other variables, to examine those chosen *in isolation*. As a result such laboratory tasks allow for no strategic re-allocation of other available resources in compensation for areas of weakness. Hence, the findings here suggest that when tests are attractive (activating) ADHD children are able to sustain attention.

The findings also support Barkley's (1997) work which maintains that the increased degree of self-control that playing video games allows, the fact that immediate reinforcement for performance from the video games is provided, and that the child does not experience a delay in gratification, are possible reasons why children with ADHD can concentrate for lengthy periods of time and are able to perform complex motor sequences just as well as non-ADHD children. Current assessment procedures using continuous performance tasks do not provide these opportunities and may therefore contribute to the severity of a diagnosis.

Academically, computer games offer teachers, clinicians and parents increased opportunities to assist children with ADHD to maximise their learning potential. Allowing these children to successfully deploy executive functions (including motor control) might increase concentration, reduce unwanted hyperactive-impulsive and inattentive behaviours, and hence increase the quantity and quality of academic work produced.

Finally, there is some evidence that video game play promotes the release of striatal dopamine (Koepp *et al*, 1998). As striatal dopamine is thought to be deficient in ADHD (Dougherty *et al*, 1999; Krause *et al*, 2000), playing video games may temporarily increase dopaminergic tone, which in turn may temporarily enhance arousal and cognitive control functions.

It is acknowledged that the present study involved boys only, and given that girls may have different executive function profiles (Houghton *et al*, 1999), the findings can only be representative of boys. In addition, although participants had equal levels of profi-

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ciency in game playing and their overall motor performance was sufficient enough to execute the movements in the game successfully, they were only allowed a limited amount of practise time. If the opportunity to practise for longer had been provided the results may have been different.

In conclusion, the present study is important in that it is the only one to date which has used a modern day platform computer video game with a design incorporating matched (on age, IQ and computer game familiarity) unmedicated boys with ADHD and non-ADHD boys to examine motor control and sequencing ability.

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