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2005-11-16

Dear Dr. Johnston:

Thank you for your thoughtful and thorough review of our revision. I hope I have now addressed all concerns.

1. I have corrected all grammatical errors and other editorial queries.
2. Sentences that were ambiguous have all been clarified.
3. Psychometric properties have been added for the DSM-IV subscales of the Connors and for the WISC/WAIS.
4. I hope the description of unsafe crossings has been clarified.
5. Due to the low internal consistency alpha for near misses, these results have been removed.
6. More information has been provided on the calculation of internal consistencies.
7. I have tried to be more cautious in the interpretations of the interactions.
8. More detail has been added on the uninterpretable interactions.
9. The references have been checked.
10. I have added some names to the end of the document of people who might be interested in reading the journal.

Many thanks for all your help.

Julia

# Road Crossing Safety in Virtual Reality: A Comparison of Adolescents with and without Attention-Deficit/Hyperactivity Disorder

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Author Note: This research was conducted in partial fulfilment for a Master's degree for the first author under the supervision of the second and third authors. Many thanks go to Stephen Murray and Gordon Simpson for their contribution to the programming of the simulator and statistical assistance.

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This study investigated the potential accident-proneness of adolescents with Attention-Deficit/Hyperactivity Disorder (ADHD) in a hazardous road-crossing environment. An immersive virtual reality traffic gap-choice task was used to determine whether ADHD adolescents show more unsafe road crossing behavior than controls. Participants (aged 13-17) were identified with (*n* = 24) or without (*n* = 24) ADHD according to a standardized protocol (K-SADS-PL and Conners Scales), with equal number of males (*n* = 12) and females (*n* = 12) in each group. ADHD adolescents did not take stimulant medication on the day of testing. Participants with ADHD had a lower margin of safety, walked slower, underutilized the available gap in incoming traffic, showed greater variability in road-crossing behavior and evidenced twice as many collisions as compared to controls. No sex differences were found. Virtual reality may help identify and educate those at higher risk of being involved in dangerous traffic situations.

KEY WORDS: ADHD, road-crossing, virtual reality

Road Crossing Safety in Virtual Reality: A Comparison of Adolescents with and without Attention-Deficit/Hyperactivity Disorder

Attention-Deficit/Hyperactivity Disorder (ADHD) is a prevalent behavioral disorder originating in early childhood, consisting of impaired sustained attention, impulsiveness, and excessive activity relative to same-aged peers (American Psychiatric Association (APA), 2000). The failure to inhibit or delay behavioral responses is often specified as the fundamental deficiency in ADHD (e.g., Nigg, Blaskey, Huang-Pollock & Rappley, 2002), causing secondary impairments in executive functioning (Tannock, 1998). These deficits in turn can lead individuals with ADHD to act without hindsight or forethought and to be less able to anticipate and prepare for future events. Diminished problem-solving ability, ingenuity and flexibility are also often evident, with these individuals appearing less flexible in their approach to problem situations and more likely to respond automatically or on impulse (Barkley & Murphy, 1998).

Given the array of neuropsychological deficits evident in ADHD populations, it is likely that this group is at substantial risk for accidental injury in many different environments. Indeed, Schwebel and colleagues (2002) determined that children with early disruptive behavior disorders, including ADHD, had twice the risk for unintentional injury as compared with boys without these diagnoses. A longitudinal study of over 10,000 children found that ADHD was specifically related to fracture injuries (Rowe, Maughan, & Goodman, 2004). Further, a number of studies have found greater driving risks associated with ADHD, with the disorder appearing to interfere with actual performance (motor control) during vehicle operation (Barkley, Murphy, & Kwasnik, 1996; Nada-Raja et al., 1997).

Crossing a road safely is a complex cognitive task involving a combination of well-developed knowledge and skills, including specific attentional control processes to assess complex traffic situations and to choose and execute appropriate responses (Dunbar, Lewis &

Hill, 1999; Oxley, Fildes, Ihsen, Charlton, & Day, 1997). The ability to safely cross the road can be considered a perceptual-motor skill, involving coordination between perception of the time-to-arrival of approaching traffic and the individual's own walking ability. Past research has shown that children and adults tend to ignore the approaching speed of oncoming traffic and predominantly use distance to judge the safety of a potential crossing (e.g., Connelly, Conaglen, Parsonson & Isler, 1998); however, this information is only appropriate if all vehicles are travelling at a similar velocity. If not, distance provides misinformation about the imminence of collision and judgements about safety are likely to be incorrect, leading to accidents. Safe pedestrian behavior requires the pedestrian to access and use relevant existing knowledge, sample and coordinate visual and auditory information, keep close control of attention, devise behavioral strategies and make complex judgements and decisions (Whitebread & Neilson, 1999).

Children who evidence difficulty in making safe road crossing judgements and have been injured in traffic accidents as a probable result of their own behavior appear more likely to be hyperactive, impulsive or inattentive than children involved in less accidents (Hoffrage, Weber, Hertwig, & Chase, 2003). DiScala and colleagues (1998) found that pedestrian injuries were the leading cause of trauma-related hospital admissions in ADHD youth. Given the amount of time adolescents spend in complex traffic environments (with walking accounting for 25% of all travel trips for those aged 5-24 years, and slightly more (28%) of trips for 10-14 year olds (Land Transport Safety Authority (LTSA), 2002)), it is important to determine whether these research findings relating to accident proneness generalize to road crossing behavior of individuals with ADHD.

Research on road-crossing behavior of individuals with and without ADHD has generally been confined to self-report measures and naturalistic tasks that do not match the properties of actual road-crossing situations. Past research has included the use of the pretend road task, which asks participant to demonstrate their normal road crossing behaviors on a constructed road within a laboratory environment (Lee, Young & McLaughlin, 1984). Other experimental paradigms have utilised the shout and two-step tasks, in which a participant stands on the curbside and indicates, either by shouting or taking two steps forward, whether they would make a road crossing under the instructions of the experimenter (Demetre et al., 1992); and observational studies of participants in actual road crossing situations (Oudejans, Michaels, van Dort & Frissen, 1996). Although the information obtained from such studies has informed our knowledge of risky pedestrian behaviors, these naturalistic tasks have inherent limitations in the type of sensory information that can be provided to participants, thereby restricting their cognitive and behavioral responses to the situation because of the physical dangers involved when crossing an actual road. They also do not permit experimental control of potentially important variables such as speed and distance of on-coming vehicles.

In contrast, the present study examined road safety using a virtual reality simulation of road-crossing situations providing a solution to some of these problems by allowing participants to cross a virtual road in the same way they would cross an actual road, but without the real-world dangers. The use of a computer-controlled simulation allows precise definition and manipulation of road-crossing characteristics, sources of visual information, and precise spatial and timing performance measures, providing direct information on actual performance and skill. McComas, MacKay and Pivik (2002) demonstrated the validity of virtual reality as a medium for training road-crossing skills by assessing transfer from desktop displays to improved road-crossing skills in the actual road-crossing environments of the participants.

Until recently, most studies on ADHD included mainly male samples and therefore, the generalizability of findings to females is limited. However, recent work investigating neurocognitive functioning of ADHD males versus ADHD females suggests that females are likely as impaired as males. ADHD females have been found to show similar functioning on tests of inhibition, spatial memory and planning, and overall cognitive abilities (Arcia & Conners, 1998); naming speed, working memory, and inhibition (Rucklidge & Tannock, 2002); and similar levels of executive dysfunction across a broad range of abilities including memory, naming speed, planning and set-shifting, and behavioral inhibition (Seidman, Biederman, Monuteaux, Valera, Doyle, & Faraone, 2005). Therefore, it is important to not only attempt to find equal numbers of males and females with ADHD in order to generalize findings to both sexes, but also to continue to allow for sex comparisons on behavioral and cognitive measures.

It was predicted participants with ADHD would have lower margins of safety than controls. Participants with ADHD were also expected to demonstrate faster walking speeds based on their impulsive nature and make significantly more unsafe crossings, due to their inherent problems with inattention, impulsivity and poorer decision-making. In addition, it was hypothesised that participants with ADHD would use less of the available gap, by choosing to cross more quickly than controls (i.e., exhibiting darting behavior), whereas control participants would take longer to gather information needed to decide whether to cross in a given gap (consequently, using a greater percentage of the gap). Participants with ADHD were predicted to show less of a learning effect across trials, as they would fail to effectively evaluate their performance due to impairments in self regulation and working memory. Further, it was expected that crossings would be safer when the distance between vehicles was small than when it is larger, across both groups, due to the observation that distance information is typically used rather than speed information by pedestrians. No gender differences were expected.

## Method

### *Participants*

A total of 49 participants were tested in this study: 24 ADHD (12 female and 12 male) and 25 controls (13 female and 12 male). One female control was excluded due to a high percentage of cautious crossings (see results), thereby reducing the sample to 24 controls. Nineteen other families were approached but did not participate for reasons including relocation (26%), refusal (49%), medical causes (5%), and no means of contact (21%). Participants were aged 13 to 17 years old. Twenty-two (88%) of the control group and 20 (83.3%) of the ADHD group were European New Zealanders. Two of the ADHD group and one of the control group were Maori. The remaining participants were of other European descents. Participants were recruited from ongoing research files of adolescents in a psychology department in a mid-sized city in New Zealand. The clinical group had been referred through a specialised service that assesses and treats youth with moderate to severe psychiatric disorders. They were first assessed by a doctorate-level clinical psychologist, and those who received a confirmed, current diagnosis of ADHD based on a standard clinical diagnostic protocol and standardised parent and teacher behavior rating scales (described below) were asked to participate in this study. The control group had been recruited through advertising at local schools and community resources and had received the same clinical evaluation as the ADHD group (see below) to confirm absence of any current or historical problems in the areas of attention, hyperactivity, and impulsivity. During recruitment, efforts were made to ensure an equal representation of males and females in each group was achieved. Participants in the two groups are also matched by age within 6 months. Sample characteristics are provided in Table 1.

Insert Table 1 about here

*Diagnostic assessment.* Semi-structured interviews were conducted with the child and parent separately, using the Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL; Kaufman, Birmaher, Brent, Rao & Ryan, 1996). This interview was used to make diagnostic decisions based on the Diagnostic and Statistical Manual –

Fourth Edition, Text Revised (DSM-IV-TR; APA, 2000) criteria. It has been validated with children and adolescents aged 6 to 17 years (Kaufman et al., 1997); test-retest reliabilities for the major Axis I disorders range from .63 to 1.00; interrater reliabilities range from .93 to 1.00; concurrent validities have been established in comparison to well-known instruments, including the Conners Rating Scales and the CBCL; and it shows comparable ratings to other structured interviews (Kaufman et al., 1997).

The long versions of the parent and teacher Conner's Rating Scales-Revised (CRS-R; Conners, 1997) were also administered and used as part of the diagnostic assessment. These scales provide a cross-informant assessment of behavior problems in children and adolescents, with an emphasis on externalising problems. The parent rating involves an 80-item scale, including measures of oppositional behaviors, hyperactivity, indices of ADHD and cognitive problems. The teacher scale consists of 59-items, providing measures of academic, social and emotional behaviors in the classroom. Test-retest of the DSM-IV subscales (those subscales used for diagnostic purposes) ranges from .67-.81 for the parent form and .47-.70 for the teacher form, internal reliability coefficients of the DSM-IV subscales range from .88-.92 for the parent form and .90 to .96 for the teacher form. These subscales have been shown to have good discriminant validity; construct validity is based on the results of a factor analysis, and considered to be acceptable; and convergent validity ranges from .95-.99 (correlations between various versions of the scales), with good criterion validity (Conners, 1997).

To be included in the ADHD group, a participant would have met each of the following criteria: (a) *DSM-IV-TR* diagnostic criteria for ADHD based on the clinician summary of the K-SADS–PL parent and adolescent interview, whereby parental report information related to the presence versus absence of externalizing symptoms would supersede the adolescent report in the event of a discrepancy, (b) a T-score ≥ 65 (a cutoff recommended in the CRS-R Technical Manual (Conners, 1997) as one indicative of a clinically significant problem) on at least one of the DSM-IV ADHD subscales of both the CRS–R parent form *and* teacher form to ensure pervasiveness of symptoms across settings, and (c) evidence of ADHD symptoms prior to the age of 7 established either through a past diagnosis of ADHD or, among new cases, through parental report and past school report cards. According to this diagnostic protocol, 8 (33%) of the ADHD group were identified as Combined Type, 3 (12.5%) as Predominantly Hyperactive/Impulsive Type and 13 (54%) as Predominantly Inattentive Type. To be included in the control group, an adolescent would have failed to meet ADHD criteria according to the K-SADS–PL and had T scores < 65 on the DSM-IV ADHD subscales of the parent and teacher form of the CRS–R.

Parents of 18 children on short-acting psycho-stimulant medication (75% of the ADHD group) were asked not to (and did not) give their child such medication on the morning of testing as stimulant medications can improve cognitive functioning of children (Berman, Douglas & Barr, 1999) and thereby confound the results. As methylphenidate has an approximate half-life of 4.5 hours (Shader et al., 1999), a 24-hour elimination period should have ensured that the majority of the active ingredient had been eliminated prior to testing. Four (14%) of the ADHD group were taking a medication other than a stimulant (e.g., clonidine, fluoxetine, citalopram) and one of the controls (4%) was taking paroxetine. These other medications were not discontinued.

*Demographic and other confounding variables*

*Socio-economic status.* The New Zealand Socioeconomic Index of Occupational Status (NZSEI; Davis, McLeod, Ransom & Ongley, 1997) was used as a measure of socio-economic status. This index assigns New Zealand occupations with a socioeconomic score (SES) from 10 (low SES) to 90 (high SES).

*Comorbid symptomatology*. The K-SADS-PL (Kaufman et al., 1996) was also used to assess the presence/absence of comorbid Axis I disorders. In the present research, a combined continuous variable that represented the presence of these disorders was derived by adding together the Axis I diagnoses for each participant. Twelve (50%) of the ADHD group had at least one other comorbid diagnosis, including Oppositional Defiant Disorder, Major Depressive Disorder, Conduct Disorder and Anxiety Disorders. Two of the controls had a comorbid diagnosis (Specific Phobia and Oppositional Defiant Disorder). As current controversy exists regarding the overlap between ADHD and Bipolar Disorder (e.g., Giedd, 2000), participants with both diagnoses were not invited to participate.

*Intelligence.* IQ was estimated using the Block Design and Vocabulary subtests of the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997) or the Wechsler Intelligence Scale for Children-III (WISC-III; Wechsler, 1991), a combination of subtests commonly used to estimate full scale IQ. Children from the larger database were not invited to participate if they had an estimated IQ below 75. Both the WAIS-III and WISC-III have excellent psychometric properties and have been shown to be both reliable and valid measures of intelligence. This two subtest combination is reportedly an accurate estimate of Full Scale IQ (FSIQ), with good reliability and validity (.91 and .86 respectively) (Sattler, 2001).

*Reading achievement.* Given the documented impact reading achievement can have on neurocognitive functioning (Rucklidge & Tannock, 2002) in addition to the high comorbidity between ADHD and reading disabilities (Stevenson, 2001), the Wechsler Individual Achievement Test Second Edition (WIAT-II; Wechsler, 2001) was used to measure word reading (assesses pre-reading and decoding skills), spelling (evaluates the ability to spell), and pseudoword decoding (assesses child's ability to apply phonetic decoding skills). The test is suitable for individuals aged 4 years to 85 years. Split-half reliability coefficients are moderate to high (.69-.98). Test-retest correlations are also rated moderate to high, with inter-scorer agreement above .79. Construct validity has been determined through intercorrelations among the subtests. Scores on the WIAT-II correlate moderately (.30-.70) with Wechsler IQ scores (Wechsler, 2001). An average of these three tests was calculated and considered as a covariate in the analyses.

*Virtual Reality Apparatus*

The virtual environment consisted of a straight, flat section of road, a street light, a tree, sky, roadside grass and 11 vehicles. The road was marked with continuous white edge lines and dashed white centre stripes that divide the road into two 3-m-wide lanes. The dimensions and spacing of the markings are based on New Zealand LTSA regulations (2002). The street light was situated directly behind the participant's starting position and the tree was directly opposite. In the crossing situation the participant encountered a line of 11 oncoming vans of different colors. The participant's body did not have a visible presence in the virtual environment. The virtual environment was generated by a 2.8 GHz Pentium 4 PC with 512-Mb of RAM and a 128-Mb GeForce4 TI 3D graphics accelerator card and is viewed through a Virtual Research Systems V8 head-mounted display (HMD) containing two full-color 3.3-cm x 640- x 480-pixel active matrix liquid crystal displays with a refresh rate of 60 frames per second, presenting a 48-degree horizontal and 60-degree diagonal field of view to each eye. The system included a 6-degree-of-freedom head tracker (Ascension Technology Flock of Birds with extended range transmitter). The base of the box holding the transmitter was 1.95 m from the floor. A receiver on top of the HMD helmet monitored the participant's head position and orientation at a sample rate of 60 times per second. Movements, either entire body or head independently, change the focus of the camera viewpoint, which determines the direction displayed in the virtual environment.

*Procedure*

The task was carried out in the main room (8.05 m wide by 8.16 m long by 2.95 m high) of the Virtual Reality Laboratory of a university psychology department. Participants were tested individually in a single session of approximately 1.5 hours duration. Consent and assent forms were reviewed and signed by both parents and adolescents for both the use of diagnostic information and for task participation. The experiment consisted of a total of 50 trials, including 8 practice trials. The first two trials were in the actual laboratory environment with the HMD resting on the participant's head without lowering the visor over the participant's eyes. This enabled the participant's walking speed to be recorded while still allowing them to see the actual environment. For Trial 1, the participant was instructed to cross the laboratory room at a normal walking speed. For Trial 2, the participant was instructed to cross the room as if in a rush. The subsequent 48 trials took place in the virtual environment with the first six being familiarisation trials. For Trials 3-5, the participant was instructed to walk towards the street light at a normal walking speed. For Trials 6-8, the participant was instructed to cross as if in a rush. For the remaining 42 experimental trials, the participant was instructed to cross when it appeared safe to do so.

There was no traffic in the six familiarisation trials and the participant was able to simply practice walking across the virtual road. After reaching the centre of the road, a pre-recorded message instructed the participant to turn around and return to the starting point. The purpose of the practice trials was to familiarise the participant with walking in the virtual environment and to obtain measures of each participant's normal and rushing walking speeds in the real and virtual environments. The walking speed data from the practice trials were also used to individuate the time-to-arrival gaps between vehicles in the experimental trials.

In the experimental trials, the participant's task was to safely cross the near lane of the virtual road in front of an approaching van. The three trials using the three distances of the vehicle (40, 50, or 60 m) were each repeated twice in a block. Seven repetitions of these 6 trials made up the 42 experimental trials, with the order of the trials randomised within each block. Each trial began with the participant facing across the road towards a street light. The participant was instructed to turn their head to the right to bring an oncoming van into view thereby initiating a trial. Eleven vans approached from the participant's right, creating 10 gaps of differing size. The first van created the first gap with a constant time-to-arrival of 1.5 s and is not included in further discussions as only the subsequent 10 gaps were manipulated. Participants had to choose when and how fast to cross the lane to avoid being hit by the approaching vans. They were asked to walk at whatever speed seemed necessary to cross the road safely. Participants were informed that a near miss would be accompanied by the sound of a car horn honking and a collision would be accompanied by a crash, similar to the sound of breaking glass. Sound level meter measurements at the earphone recorded the horn honk at 90db and the crash at 77db. After each trial, the participant was instructed to prepare for the next trial by a black screen with white text and the recorded verbal message "Turn right and get ready to cross." A red strip of tape on the floor was used as a way for participants to reposition themselves at the beginning of each new trial. Van velocity was varied to create the times-to-arrival for each participant based on: *Van velocity = distance / time-to-arrival.*

Hence, van velocity was controlled by the experimental design but varied between participants, as the times-to-arrival were individuated. Normal and rushed walking speeds were used to determine the range of individuated times-to-arrival, so that each participant would be confronted with temporal gaps appropriate to that individual's range of walking speeds. Vans of different colors were also randomized within each block. Three levels of distance of 40, 50, or 60 m were randomised across trials within each block. The distance (in space) between vans in a traffic flow was the same for each pair of vans in a given trial.

As simulation sickness, a condition similar to motion sickness, is a potential problem arising from the use of virtual reality, participants were made aware of the potential risks of simulation sickness and advised that they could withdraw from the experiment at any stage if they felt unwell. As a precaution, participant transportation to and from the University was organised prior to participation, ensuring participants would not be driving themselves. Based on questionnaire, there was no indication of significant sickness caused by the simulation and no participants withdrew from the experiment.

*Dependent measures*

*Margin of safety.* The margin of safety indexes the relative safety of the participant's road crossing in the temporal domain. It is derived from the safety ratio; the ratio of available crossing time (time-to-arrival of the vehicle) to actual time taken to cross: *Margin of safety (%) = (safety ratio – 1) × 100.* The safety ratio is a ratio of an environmentally controlled variable (time-to-arrival) to an individually controlled variable (time-to-cross) and is a dimensionless measure. For example, if the initial time-to-arrival of the van was 5 s, and the participant crossed to a safe position in 4 s, then the safety ratio would be 5 s / 4 s = 1.25 which is a 25% margin of safety. If time-to-arrival and time-to-cross were equal, e.g., 5 s / 5 s = 1.00, the margin of safety is 0% specifying imminent collision). If the initial time-to-arrival of the van was 4 s, and the time needed to cross was 5 s, then the safety ratio would be 4 s / 5 s = 0.80, so that the margin of safety is -20% specifying an unsafe crossing.

Time-to-arrival ($T_a$ ) of each vehicle is the interval between when the previous van passes the participant's intended crossing path and when the next van arrives at the crossing path: *Time-to-arrival = shortest time-to-cross x [1 +* $T_a$ *Factor x (Van number - 1)].* The time-to-arrival factor is a value that determines the level of $T_a$ for each subsequent van and the number of vans (Van number) selects the range of values. This equation means that the shortest $T_a$ will be equal to the shortest time available in which to cross (for the first van). For example, if the value is set at 0.1 and the shortest time to cross in a practice trial was 3 s then the first gap would be 3 s, the second 3.3 s, then 3.6, 3.9, continuing to increase for as many vans as there are in the traffic flow. *Time-to-cross* is the difference between when the participant moves 0.5m forward from the starting point and when the participant passes the far edge of the van's extent in the lane (i.e., has reached a safe position). The 0.5-m distance was used to avoid false trial initiations due to body sway.

*Walking speed.* Walking speed was defined as the speed (in metres/second) at which the participant crossed the road, averaged over the distance from 0.5m forward of the starting position to the middle of the road. Walking speed was recorded to compute time-to-cross, and also to compare the two groups.

*Unsafe crossings.* A crossing which resulted in either a collision or a near miss was classified as unsafe. The participant was considered to be hit if the camera viewpoint fell within the length and width (but not height) of the outer bounds of the van's position. A near miss was operationally defined as the participant being within 0.5 seconds of being hit by the same criterion.

*Percentage of Gap used*. By the time a participant begins to cross, part of the initial time to arrival of the van has elapsed. The time remaining is expressed as a percentage of the original temporal gap available in which to cross: *Percentage of gap used = [($T_a$ of van when participant begins crossing) / (initial $T_a$ of van)] x 100*. If the available gap was 2 s, and the participant waited 0.5 s before crossing, the percentage of gap used would be 75%.

Internal consistency estimates for this task give an index of the reliability of the task; cronbach alphas were calculated: .90 for margin of safety, .98 for walking speed, .40 for near misses, .80 for collisions, and .93 for percentage of the gap used. Validity is established via observations of specific behaviors during the task. For example, speed of walking in the virtual environment and normal environment were compared and no differences were found in walking speeds suggesting that immersion in the task was successful. Cautious crossings (not crossing until all the vans have passed) were also observed and given that approximately 5% of crossings were cautious (see results below), this provides further evidence of the fidelity of the simulation and participant's confidence and immersion in the virtual environment.

## Results

Although not explicitly stated, it was implied that participants were to cross before all the vans passed since they were told to cross in a gap they perceived to be safe. Only the trials where the participant crossed before all the vans passed could be used in the analyses (because four of the dependent variables require information about the gap crossed in). However, it was deemed of greater importance to allow the participants to behave in a way that more closely resembled their real-world behavior (and suggesting that they were immersed in the simulation) than to attempt to minimise unusable data trials. One control participant, who engaged in cautious crossings on 64% of the trials was removed from further data analysis and replaced by a new participant. Waiting until all of the vans had passed defines a cautious crossing. Ninety eight data points (4.86% of the total) for cautious crossings by other participants were replaced by the nearest similar data point for that participant. For example, missing data in a 40-m distance trial would be replaced by data from the same type of trial, preferably from an earlier trial as it was expected that this would lead to a more accurate representation of change over time. This technique reduces some of the variability within a participant's data, but since the replacement data has come from their own performance, variability between participants is maintained. Replacements were equal across the two groups.

As presented in Table 1, there were no group differences in age. There were group differences in SES, with control participants and their families having a higher SES than the ADHD group. There were also group differences in estimated IQ. The ADHD group had a lower mean IQ than the control group. Group differences were found in comorbid diagnoses per group, with the ADHD group having more comorbid diagnoses than the controls. Further, group differences were also found on reading achievement with the ADHD group showing poorer reading skills than the controls. As all these variables could contribute to group differences on the crossing task, analyses were run with and without these variables (SES, IQ, comorbidity, and reading achievement) included as covariates in order to assess the individual contribution of each of these variables to the results.

Each dependent variable was analysed with a 4-way Group (2) x Sex (2) x Distance (3) x Block (7) ANOVA with repeated measures on the last two factors. A *p* value less than .05 was considered a significant difference. Effect sizes (ES) were calculated using G*Power ($f^2$) where .02, .15, .35 indicate small, medium and large effect sizes respectively. Covariates were then considered using ANCOVAs.

*Margin of safety.* For the margin of safety data, analysis of main effects of group, distance, and block were significant. There was no significant sex difference. There was no significant group by block interaction. The block by distance interaction was also significant, $F$ (12, 552) = 1.79, $p < .05$; however, inspection of the data suggests that a few rogue data points led to the significant interaction, making the pattern uninterpretable. The main effect of group, $F$ (1, 44) = 4.31, $p < .05$, $ES = .09$, shows that there was a significant difference between the margins of safety of participants in the ADHD (56.7%) and control (69.5%) groups. Since times-to-arrival of the vans were individuated, it is worth noting that the mean times for the ADHD and control groups were 2.72 sec and 2.63 sec, respectively, so that the imminence of collision was actually slightly lower on average for the participants with ADHD. In other words, the ADHD group was actually facing a less challenging task than the control group but still performed poorer.

There was a main effect of distance between vans, $F$ (2, 88) = 47.106, $p < .001$, $ES = 1.07$. Participants had mean margins of safety of 76%, 61% and 52% at the 40-m, 50-m and 60-m distances, respectively. The main effect of distance between vans indicates that participants believed that there was more time available to cross the road as distance increased, when in fact the time was the same for all distances. Mean margins of safety increased across the seven blocks of the experiment, from 45% in Block 1 to 76% in Block 7, $F$ (6, 24) = 10.311, $p < .01$, $ES = .23$, indicating that both groups improved with practice.

The analyses were rerun controlling for covariates; while comorbidity and SES did not change the results, reading achievement and IQ eliminated the group differences found on margin of safety, suggesting these variables may also impact on safe road crossing. One interesting finding that strengthened when controlling for comorbidity was the group by block interaction, $F$ (6, 270) = 2.31, $p$

<.05, showing that the performance of the ADHD group varied across time; this variable performance was not present in the control group (see Figure 1).

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Insert Figure 1 about here

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*Walking speed.* A comparison of the walking speeds of the two groups revealed a significant difference, $F$ (1, 44) = 4.42, $p < .05$, $ES = .1$. Control participants walked significantly faster with an average speed of 1.93 ($SD$ = 0.35) m/sec compared to 1.73 ($SD$ = 0.37) m/sec for participants with ADHD. There were no sex differences. No interaction with group was significant. This group difference was unchanged controlling for SES, IQ, reading and comorbidity.

*Unsafe crossings*. Near misses and collisions index unsafe crossings. As the internal consistency estimates of near misses was low, only collisions were interpreted. For collisions, the main effects of group, distance, and block were all significant, as well as a significant interaction of block with distance, although this latter interaction was uninterpretable. The significant main effect of group, $F$ (1, 44) = 5.45, $p < .05$, $ES = .12$, showed that the ADHD group had more collisions than the control group. The controls had collisions in 5.7% ($SD$ = 8) of the trials compared with 12% ($SD$ = 14.6) of the ADHD group. The main effect of distance, $F$ (2, 92) = 58.51, $p < .001$, $ES = .12$, showed that as distance increased, the number of collisions also *increased,* indicating unsafe crossings occur more frequently when the van was further away. This latter result suggests that collisions were not deliberate by one specific group; otherwise, collisions would have occurred at an equal rate regardless of van distance. The significant main effect of block, $F$ (6, 276) = 5.17, $p < .001$, $ES = .12$, showed that as the trials increased, the number of collisions decreased, indicating a learning effect for both groups.

Analyses were rerun controlling for covariates. While group differences for collisions remained, one interaction strengthened and became significant. After controlling for reading achievement, a block by group interaction emerged, $F$ (6, 270) = 2.48, $p < .05$. One interpretation is that the ADHD group is showing variable performance in rates of collisions across time (see Figure 2).

Insert Figure 2 about here

*Percentage of the gap used.* There were significant main effects for group, distance, and block as well as significant interactions for block with group, and for block with distance. On average, the control group used 75% of the available gap compared with 70% of the ADHD group, $F$ (1, 44) = 3.996, $p < .05$, $ES$ = .09. Participants used significantly more of the available gap at closer distances than further away, $F$ (2, 88) = 70.509, $p < .001$, $ES$ = 1.6; 77%, 72%, and 69% of the available gap at the 40-, 50- and 60-m distances, respectively. The significant interaction between block and group, $F$ (6, 276) = 2.8, $p < .05$, revealed a relatively steady increase for the control group, whereas the percentage decreased for the ADHD group at mid-session followed by a second rise (see Figure 3), again illustrating the variable response pattern of the ADHD group. While the block by distance interaction was significant, $F$ (12, 552) = 2.42, $p < .01$, the data were uninterpretable. While reading achievement, IQ and comorbidity each eliminated the significant group effect, the interaction between block and group remained significant. Further, a significant distance by group interaction emerged after controlling for both reading and comorbidity, $F$ (2, 90) = 4.85, $p < .01$, with the ADHD adolescents using less of the available gap, the greater the distance between vans.

Insert Figure 3 about here

Discussion

This study is the first to assess the road-crossing behavior of adolescents with and without ADHD in a simulation of an everyday traffic situation using virtual reality. Adolescents with ADHD evidenced lower margins of safety, walked slower crossing the virtual road, made more unsafe crossings, primarily due to substantially more collisions with oncoming vehicles, and used less of the available gap when making a crossing as compared with the controls. Indeed, over 40% of the road crossings made by the ADHD adolescents resulted in low margins of safety, suggesting that these individuals are at substantial risk for accidental injury in traffic environments, particularly in comparison to their peers. Further, in the virtual reality environment, the ADHD group were hit *twice* as often as controls. Medium effect sizes confirm the magnitude of the differences found. As predicted, no sex differences were observed, consistent with more recent research on executive functioning and girls with ADHD (e.g., Seidman et al., 2005).

The analyses were rerun using IQ, reading achievement, SES, and comorbidity as covariates to determine the impact each had on the results found. Reading achievement and comorbidity had the greatest impact on the results. It was not unexpected, given the high rates of comorbid diagnoses and reading problems in ADHD samples, that some group effects would be eliminated when controlling for these variables. These results imply that to some degree, *all* of these variables contribute to unsafe road-crossing. While this does suggest that some of the group differences found may not be solely caused by the presence of ADHD, nonetheless, it does not eliminate the existence of these problems in individuals with ADHD. The effect reading achievement had on the results indicates the need to investigate road crossing behaviors in other psychiatric groups, particularly in children with reading disabilities, given that they are known to have cognitive deficits not dissimilar to the ADHD population (Rucklidge & Tannock, 2002).

Interestingly, when controlling for these other variables, the interactions between group and block emerged or strengthened, highlighting variable performance as a potentially important theme in the deficits associated with ADHD.

The finding that adolescents with ADHD frequently make unsafe decisions, even under almost optimal road-crossing conditions that included unobstructed view, few distractions and making decisions about traffic travelling in only one direction, is a matter of considerable concern (Connelly et al., 1998). In the real-world road-crossing context, the adolescent has to consider traffic approaching from both directions and cope with many distractions, as well as coping with obstructions to their view. Any of these factors may further reduce the accuracy of their road crossing judgements. The potentially hazardous road crossing decisions, the underutilization of the available gap and the lower margins of safety by our participants with ADHD are consistent with the associated impairments commonly found in ADHD, including attention, time perception and behavioral inhibition deficits (Barkley, Koplowitz, Anderson & McMurray, 1997; Nigg et al., 2002). These results also present as extensions of the findings that associate ADHD with driving related deficits (e.g., Barkley, 2004; Barkley et al., 1996; Cox, Merkel, Kovatchev, & Seward, 2000; Nada-Raja et al., 1997) and self-reports of more lapses and dangerous errors while driving, and driving violations (Reimer et al., 2005).

It appears that participants with ADHD have greater perceptual difficulties in judging the time-to-arrival of oncoming vehicles. Even more than the controls, they tended to focus on task-irrelevant distance in anticipating relative arrival time of approaching vehicles, which is informed solely by relative rate of optical expansion. Individuals with ADHD may make hazardous decisions about vehicle approach times because they are unable to accurately appreciate the interrelationships among event duration, velocity and distance. The difficulties evidenced by ADHD adolescents in using the available gap to cross safely between vehicles may also be related to impairment in sense of timing and associated executive function deficits documented in ADHD individuals (Toplak, Rucklidge, Hetherington, John & Tannock, 2003; Barkley et al., 1997). Estimating temporal event durations and using them to regulate the timing of motor responding is thought to require the retention of sequences of information in short-term or working memory, both of which have been shown to be deficient in ADHD individuals (Tannock, 1998).

Although both controls and participants with ADHD chose similar sized gaps to cross in, participants with ADHD used less of the available gap to cross the road and walked slower. These results suggest that Participants with ADHD were not as adept at judging when it was safe to cross the road or what walking speed to use to cross safely. Although this road crossing behavior was not predicted, as it was expected adolescents with ADHD would be more impetuous and rush across the road, the findings are consistent with research utilizing the STOP task showing that adolescents with ADHD have slower stop-signal reaction times, milder problems in the 'go' process and slower processing speed (Nigg, 1999; Schachar, Mota, Logan, Tannock, & Kim, 2000). If, as suspected, participants with ADHD are attending more to irrelevant information, they would walk slower because they believe they have more time than is actually available.

Adolescents with ADHD were not only more willing to cross in front of approaching vans despite risk, but they also experienced more collisions when crossing than their control peers. Situations in traffic environments often require frequent shifts in the focus of attention and sudden changes in behavior (e.g., having to start running rapidly to avoid an automobile after walking across on a previously deserted road) (Cepeda, Cepeda, & Kramer, 2000). One might expect that both the inhibition of a previously performed task and the rapid preparation for a new task would be more difficult for those with ADHD. Due to the random trials used in the design of this experiment, the crossing demands for participants changed unpredictably and often, thereby requiring participants to constantly re-evaluate the speed at which to cross and the time they had to do so safely. Examination of the mean scores of participants across the blocks of the experiment revealed that those with ADHD were slower to adjust their behavior and showed more variability in response, with control participants showing a steeper learning curve. Consistent with previous research of variable attentional focus and ADHD (Barkley, Edwards, Laneri, Fletcher, & Meteria, 2001; Zakay, 1992), this study also found variability in performance across time for the ADHD group, significantly influencing the consistency of safe road crossing.

*Limitations*

Due to the small sample size per group, only a limited number of analyses could be conducted within groups. Although desirable, it was not possible to compare between the subtypes of ADHD or those with different comorbid diagnoses. There has been suggestion in the literature that hyperactivity may not be directly related to rates of injury (e.g., Davidson, 1987). The high percentage of inattentive participants in this sample suggests that inattention may prove to be a more important variable in predicting safety in road crossing; however, this hypothesis could not be tested. Given that the sample was limited to adolescence, we cannot generalize the results to younger and older participants with ADHD.

There are some limitations and drawbacks inherent in using VR equipment. The HMD may limit the adequacy of the simulation of an actual road-crossing situation. However, participants should have been able to learn to adapt to the restrictions of the equipment, as when carrying heavy objects like a book bag, and choose an appropriate walking speed. In addition, the information available in the simulation does not fully match that available in real-world crossing situations. This is most noticeable in the field of view afforded by the HMD, which is 48 degrees compared to approximately 180 degrees in the real world. The narrower field of view could, however, have a positive influence on attentional behavior by forcing the participant to turn the head in the direction of oncoming traffic, a part of training to cross safely (McComas et al., 2002). As virtual reality technology becomes more sophisticated, such restrictions in view will likely be reduced and the simulation will become even more realistic. Finally, alternative explanations for the results found cannot be ruled out. For example, differential levels of motivation could have influenced one group over the other; alternatively, it is possible that the ADHD group enjoyed the visual and auditory feedback inherent in collisions and near misses, inadvertently resulting in poorer performance in some trials.

*Future Investigations of ADHD*

Relative to control adolescents, those with ADHD may not be as good at crossing the road as they cannot accurately estimate distance in time, rather than distance in space. Future studies could clarify the nature of this impairment by investigating suppression of attention to irrelevant information and behavioral inhibition in ADHD and control adolescents in relation to their performance on a road-crossing task. In addition, research could employ a design in which participants are tested on and off medication to determine whether medication improves road crossing performance and reduces the risk of injury for those with ADHD to be at least equivalent to that observed for control participants. In order to further add to our understanding of ADHD and the association with risk in traffic environments, self-report measures and traffic data from government databases could be obtained. Self-report measures could include evaluations of attitudes towards road safety, knowledge of appropriate traffic behavior and estimates of outcomes of various traffic scenarios in addition to information on self awareness of lapses and errors to verify whether participants are aware of the errors they are making (Reimer et al., 2005). To determine the extent to which the findings of this study generalize to actual traffic situations and other situations (i.e., driving a vehicle), future studies could compare these results with injury statistics from hospital records. Future investigations could also determine the extent to which performance is influenced by fatigue or boredom, rather than specific skill deficits.

*Clinical Implications*

In an attempt to design approaches to traffic education for children and adolescents, research should systematically link disorder- and age-related cognitive abilities (or lack thereof) to the specific abilities necessary to cross a road safely. This may include exhibited deficits in perception (i.e., of event duration or imminence of collision), attention (i.e., higher distractibility, suppression), and behavioral factors (inhibition, self-regulation) that might put individuals at risk in the traffic environment. To be most effective and successful, such interventions should occur at the point of performance and in the most realistic setting available. A behavioral intervention employing virtual reality technology may prove to be a more effective way of teaching appropriate behavior than a seminar based, educational intervention. The instant behavioral feedback provided by virtual reality, such as the sound of a horn honking or a crash, as well as awareness of a safe crossing, may serve as a means of enhancing motivation and self-regulation skills for those with ADHD as well as helping increase their awareness of the dangers in their surroundings. Pedestrian injuries remain an important health problem, and any strategy to protect those at most risk of danger would have an enormous impact. At the very least, advice to those identified as ‘at risk,’ regarding precautions in the traffic environment, would be justified.

Given that young people with ADHD are more at risk and involved in more accidents than their non-ADHD cohorts, they might be considered to have risk-taking personalities. However, the road-crossing results of the present research instead suggest that they are less likely to consistently make safe road crossing decisions under optimal conditions, perhaps because of variable motivation, difficulty sustaining attention and impulsivity. Whereas personality characteristics are resistant to change, variable performance could be improved with training, practice, and feedback. Virtual reality simulations provide a rich resource both for investigation of training procedures and for their application to improve a skill. We can be optimistic that the safety of those with ADHD can be increased in road crossing environments.

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Table 1

*Sample characteristics of the ADHD and Control groups.*

| | ADHD | | Control | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | t value (1, 46) |
| Age | 14.92 | 1.21 | 15.00 | 1.32 | 0.23 |
| NZSEI | 45.58 | 20.74 | 57.83 | 20.19 | 2.07* |
| Estimated IQ | 96.58 | 15.03 | 108.13 | 15.03 | 2.81* |
| WIAT-II average reading | 90.72 | 13.69 | 106.28 | 11.80 | 4.272** |
| Comorbid diagnoses | .87 | .87 | .08 | .27 | 4.419** |
| CPRS-R (T scores) | | | | | |
| DSM Inatt | 78.04 | 12.68 | 50.00 | 8.15 | -8.93** |
| DSM Hyp/Imp | 71.91 | 11.79 | 50.26 | 9.93 | -6.74** |
| CTRS-R (T scores) | | | | | |
| DSM Inatt | 68.11 | 14.81 | 50.50 | 11.63 | -3.46** |
| DSM Hyp/Imp | 64.72 | 18.21 | 52.83 | 13.66 | -1.93 |
| K-SADS (# of symptoms) | | | | | |
| Inatt Current | 6.17 | 2.51 | 0.54 | 1.44 | -9.51** |
| Inatt Past | 6.83 | 2.39 | 0.08 | 0.41 | -13.64** |
| Hyp/Imp Current | 4.29 | 2.93 | 0.38 | 0.82 | -6.31** |
| Hyp/Imp Past | 5.92 | 2.90 | 0.29 | 0.69 | -9.24** |

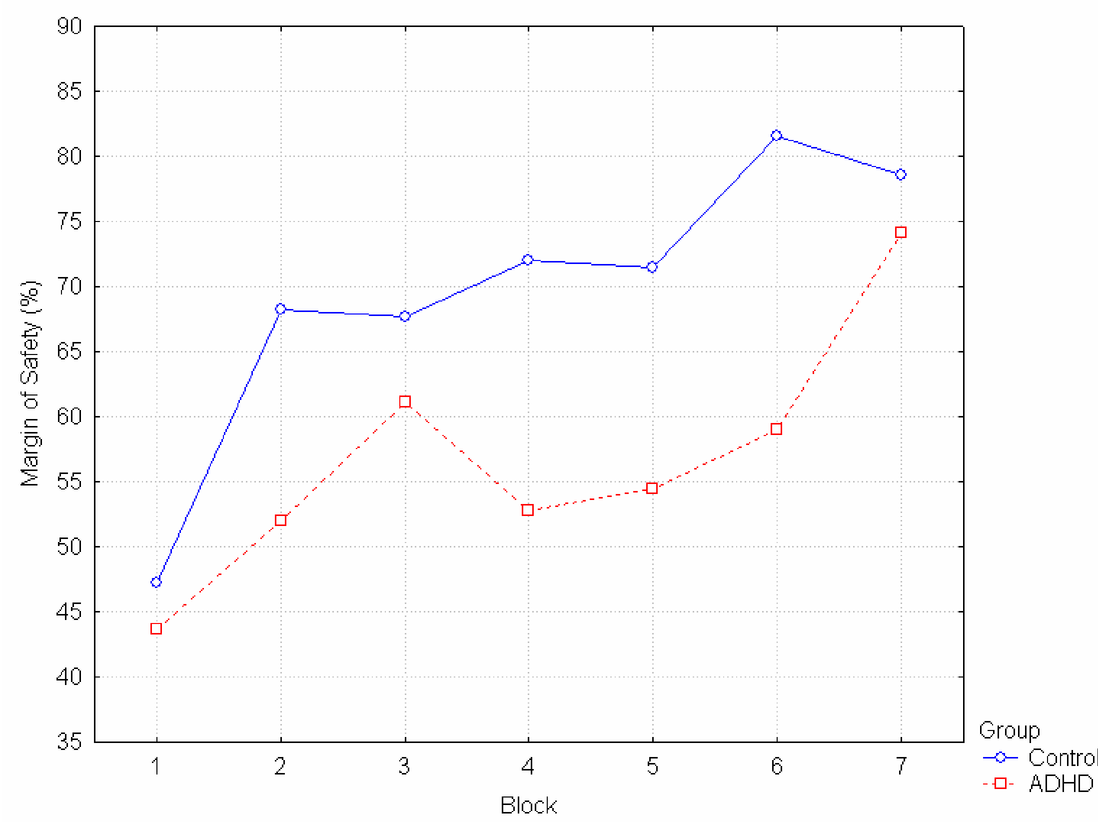
NZSEI = New Zealand Socioeconomic Index of Occupational Status, WIAT-II = Wechsler Individual Achievement Test, CPRS-R = Conners Parent Rating Scale - Revised, CTRS-R = Conners Teacher Rating Scale – Revised, K-SADS = Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime, Inatt = inattentive, Hyp/Imp = hyperactive/impulsive, SS = standard score, * $p < .05$, ** $p <.001$.

Figure Captions

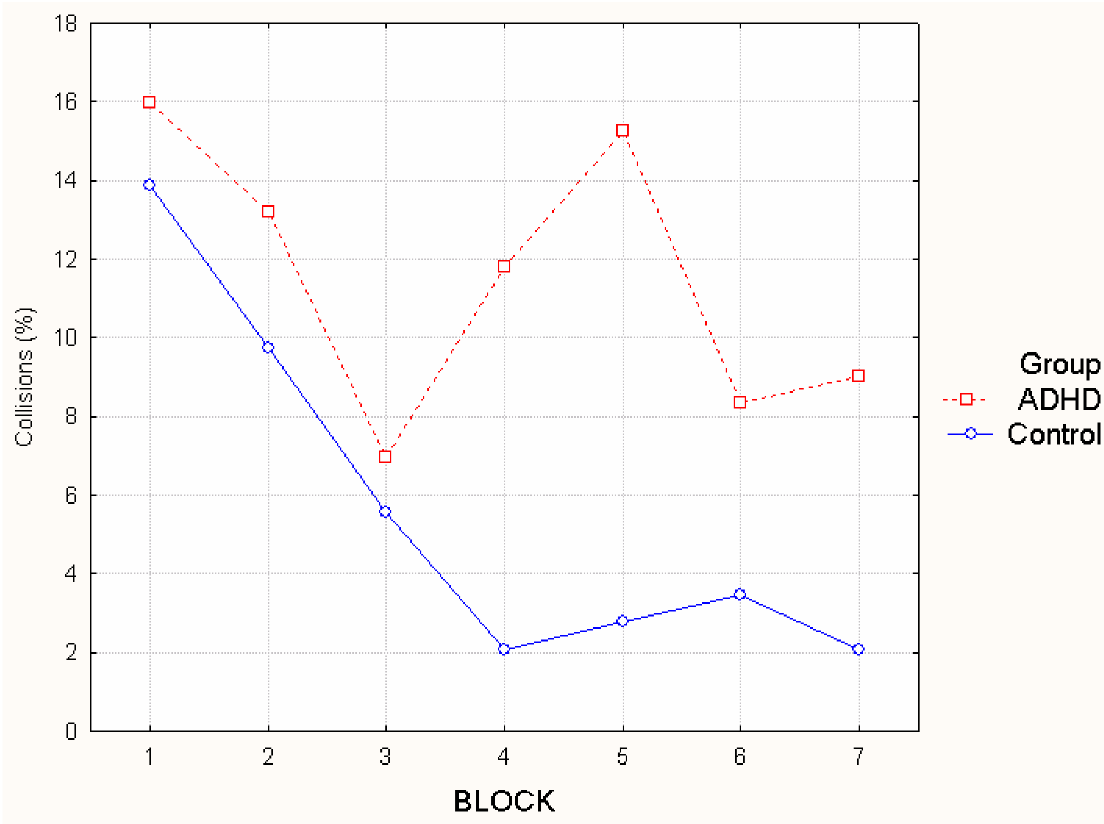
*Figure 1.* Margin of safety as by group and block.

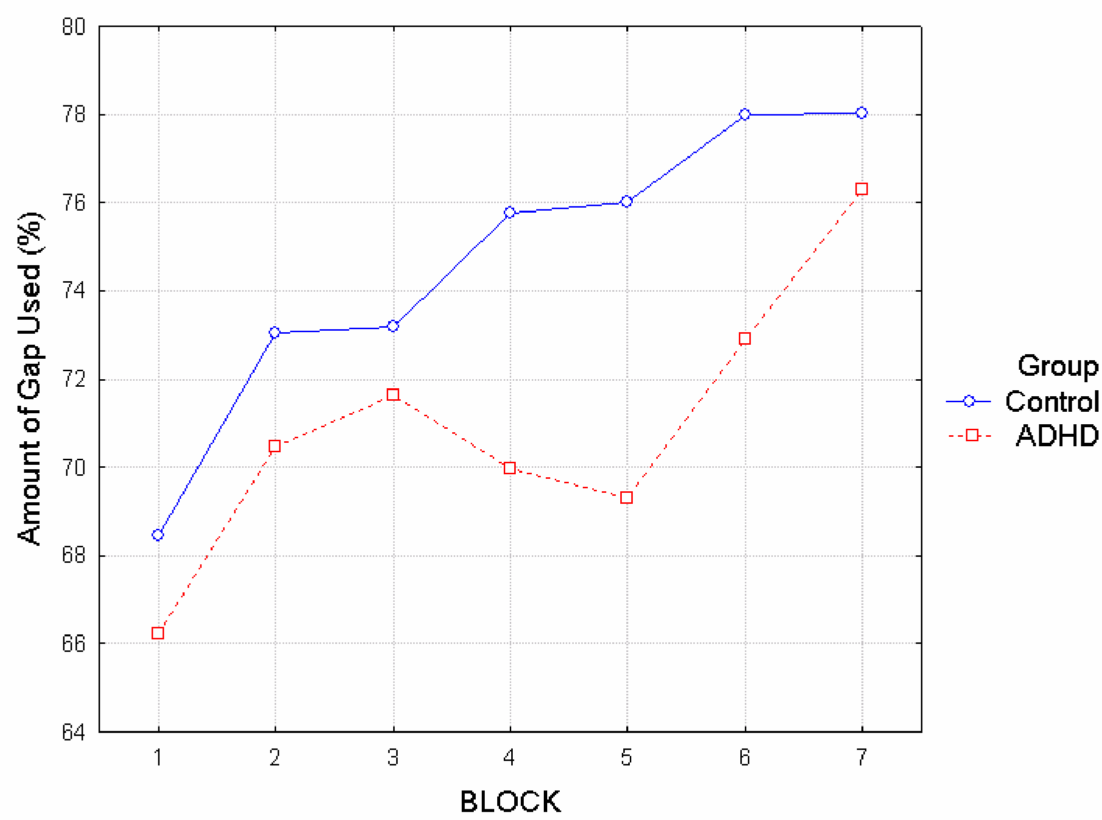
*Figure 2.* Percentage of collisions by group and block.

*Figure 3.* Percentage of the available gap used by group and block.



90
85
80
75
70
65
60
55
50
45
40
35
Margin of Safety (%)
1
2
3
4
5
6
7
Block
Group
Control
ADHD


18
16
14
12
10
8
6
4
2
0
Collisions (%)
1
2
3
4
5
6
7
BLOCK
Group
ADHD
Control


80
78
76
74
72
70
68
66
64
Amount of Gap Used (%)
1
2
3
4
5
6
7
BLOCK
Group
Control
ADHD

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