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Behavioral and Cardiovascular Responses to Frustration During Simulated Driving Tasks in Young Adults With and Without Attention Disorder Symptoms

Michele L. Oliver[1], **Joel T. Nigg**[2], **Nicholas D. Cassavaugh**[1], and **Richard W. Backs**[1]

[1]Central Michigan University, Mount Pleasant [2]Oregon Health and Science University, Portland

Abstract

Objective—The present study examined the role of negative emotions on driving performance in relation to ADHD, by comparing young adults scoring high on measures of ADHD (n = 20) with a control group (n = 22).

Method—The authors used cardiorespiratory physiological measures, simulated driving behavior, and self-report to examine how participants with high and low ADHD symptoms responded to frustration and to determine how frustration affected simulated driving performance.

Results—Groups did not differ in *operational* driving skills, but participants with high ADHD symptoms reported more frustration and exhibited more impairment at the *tactical* level of driving performance than the controls. There was significant suppression of respiratory sinus arrhythmia from resting baseline during tasks, but it did not differ between groups during driving.

Conclusion—This article proposes that remedial driver training for ADHD populations should focus more on the control of negative emotions rather than on attention or fundamental driving skills.

Keywords

ADHD; negative emotions; simulated driving performance; respiratory sinus arrhythmia

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ADHD is a common psychiatric disorder characterized by inattentiveness, excessive motor activity, and impulsivity (Diagnostic and Statistical Manual of Mental Disorders (4th ed., text rev.; *DSM-IV-TR*; American Psychiatric Association [APA], 2000). Furthermore, a salient theme in the recent literature has been the role of emotional dysregulation in ADHD (Barkley, 2010). Although ADHD is primarily diagnosed in school-aged children, it is estimated that 4.4% of adults in the United States (up to 70% of childhood-diagnosed cases)

Corresponding Author: Michele L. Oliver, Department of Applied Experimental Psychology, Central Michigan University, 101 Sloan Hall, Mount Pleasant, MI 48859, michele.oliver@cmich.edu.

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have ADHD (Kessler, Adler, Barkley, et al., 2006). Oftentimes, the symptoms increase in severity with age and can lead to impairments in academic performance and emotional development (Waschbusch et al., 2002) as well as to high rates of antisocial behavior, mood problems, and significantly to public health, and automobile accidents (Barkley, 1998; Barkley, 2004; Nigg, 2006). Barkley (2004) found that adults with ADHD are at a sixfold increase in risk of adverse driving outcomes, such as greater numbers of traffic citations, vehicular crashes, and suspended or revoked licenses, compared with drivers without the disorder (see Richards, Deffenbacher, & Rosen, 2002).

Barkley (2003) concluded that both symptom dimensions associated with ADHD (i.e., inattention and hyperactivity-impulsivity) are significantly associated with an increased risk of unsafe driving and vehicular accidents. However, it remains unclear what mechanism drives this phenomena—for example, cognitive lapse due to inattention is one hypothesis. Alternatively, the relationship between ADHD and poor driving performance might be explained by poor self-regulation, including impulsivity and poorly regulated negative affect (such as anger, hostility, and aggression).

There is ample reason to suspect inattention as a mechanism. Many automobile accidents are caused by driver inattention (Trick, Enns, Mills, & Vavrik, 2004), which can manifest in a number of ways. The driver may (a) be engaged in a task that is secondary to driving (e.g., talking on the phone, looking at a map), (b) pay attention to the driving task but not to a critical aspect of driving at an inopportune time, or (c) momentarily glance away from the forward roadway but at no specific object or person (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). Thus, inattention is one plausible hypothesis for ADHD-related driving problems.

However, a previous study (Oliver, 2007) examined the relationships between self-reported ADHD symptoms, negative emotions, disinhibition (i.e., emotional dysregulation), and driving outcomes and found that the presence of negative emotions and disinhibition in young adults had full and partial mediating effects on the relationship between ADHD symptoms and self-reported driving anger and safe-driving behavior, respectively. These findings suggested that young drivers with attention disorder symptoms exhibit more driving-related anger and fewer safe-driving behaviors because of their higher levels of trait anger and disinhibition. Note that these traits are associated with the hyperactive-impulsive dimension, rather than the inattention symptom dimension in the two-dimension ADHD framework (Martel, von Eye, & Nigg, 2010).

Relatedly, Walcott and Landau (2004) found that disinhibition in children with ADHD is associated with increased levels of anger, reactive aggression, and disruptive behaviors (Waschbusch et al., 2002). Walcott and Landau discovered that, in emotionally charged situations, children with ADHD could not keep from having outbursts and publicly announcing their frustration, even when specifically instructed to suppress their emotions. Thus, the inability to control responses to frustration is an alternative and plausible hypothesis for explaining poor driving in ADHD.

One can conceptualize difficulty in controlling emotional arousal as a form of disinhibition. Because disinhibition is characteristic of disorders such as ADHD, there may be specific effects of disinhibition on psychophysiological responsivity for individuals with the disorder (Beauchaine, 2001). Iaboni, Douglas, and Ditto (1997) examined psychophysiological responses to reward and extinction in children with and without ADHD. During resting baseline, Iaboni et al. found no group differences in heart rate and skin-conductance levels. During reward, all children experienced increases in heart rate; however, these rates quickly decreased toward baseline levels for children with ADHD. In addition, during extinction, control children had significant increases in skin conductance from baseline, whereas children with ADHD showed no significant changes in skin conductance compared with baseline levels. Overall, these results provided evidence for reduced psychophysiological responding in heart rate and skin conductance levels for children with ADHD.

Beauchaine (2001) suggested that reduced physiological responding, particularly vagal tone, is associated with emotional disinhibition. Children with ADHD experience higher levels of emotional reactivity and frustration than matched controls (Walcott & Landau, 2004). In addition, children with ADHD oftentimes cannot gauge their own heightened emotional levels, resulting in more explosive outbursts that appear to be disproportionate to the situation (Barkley, 1997). Because differences exist in frustration (Walcott & Landau, 2004) and in physiological responding (Iaboni et al., 1997) between children with and without ADHD, we hypothesized that similar phenomena might occur for young adults with high ADHD symptoms during simulated driving.

Three identifiable behavioral subtypes underlying the symptoms associated with ADHD in children (APA, 2000). The validity of these subtypes in children has been called into question by their instability (Lahey, Pelham, Loney, Lee, & Wilcutt, 2005), and there are limited data on their validity in adults (Barkley, Murphy, & Fischer, 2008). In contrast, validation remains strong for the distinction between the two symptom dimensions: inattentiveness/disorganization and hyperactivity/impulsivity (Lahey & Willcutt, 2010). Furthermore, there is evidence that ADHD may reflect a cut point on a trait dimension that is continuously distributed in the population (Levy & Hay, 2002). In light of these considerations, the current study focused on global composite symptom levels. However, we also considered whether the two-symptom domains provided additional information about driving behavior for participants with high ADHD symptoms.

The present study used cardiorespiratory measures while participants with high and low ADHD symptoms completed a simulated driving task designed to elicit frustration. We examined group differences in self-reported frustration, driving anger, and physiological response in relation to driving performance during simulated driving. We also asked whether driving performance can be explained by either of the two symptom dimensions of ADHD (for those participants with high ADHD symptoms) or by the presence of frustration, conceived as a dimension of negative emotion that is at least partly separable from the two ADHD symptoms.

With regard to driving itself, it is important to recognize that it is not a single-domain construct. We were guided by a model proposed by Michon (1979), who identified three hierarchical levels of driving performance: operational (fundamental skills such as attention and concentration), tactical (skills used while driving in traffic, that is, adjusting to environmental conditions), and strategic (involving route planning, forethought, etc). Individuals with ADHD are more likely to receive traffic citations, are more likely to demonstrate more reckless driving, are four times more likely to be involved in a crash while driving, and have more frequent adverse driving outcomes than matched controls (Barkley, 2004; Richards et al., 2002). According to Trick et al. (2004), these behaviors describe behaviors at the tactical level of vehicle operation where drivers demonstrate more impulsive behaviors and an inability to adjust their behavior as driving demands change. Therefore, we expected that participants with high ADHD symptoms would self-report more driving anger and higher frustration levels and would have reduced physiological reactivity during simulated driving performance, when compared with participants with low ADHD symptoms. Last, we expected that participants with high ADHD symptoms would have more impaired driving performance, particularly at the tactical level of vehicle operation because of the presence of negative emotions and not due to inattention

Method

Participants

Participants were 42 students (10 men and 32 women) from a medium-sized Midwestern university who were called back from a previous study (Oliver, 2007) conducted 12 to 18 months before, when they were freshmen. These participants had been initially recruited because they were enrolled in Introduction to Psychology classes and were recruited via the Department of Psychology Subject Pool. Self-reported scores from the Current Symptoms Scale from Time 1 (Barkley & Murphy, 1998) were screened, and participants who reported either (a) very low attention disorder symptoms or (b) very high attention disorder symptoms were called back to participate in the current study (Time 2 in Table 1). A total of 22 participants were classified as having “low” ADHD symptoms (meeting none of the diagnostic criteria for having ADHD based on self-report). The remaining participants (n = 20) were classified as having “high” ADHD symptoms, exceeding the recommended threshold for ADHD symptoms for either inattention or hyperactivity (APA, 2000) based on self-report on the same scale.

Participants ranged in age from 19 to 26 years (M = 20.5 years, SD = 1.5). In the low ADHD symptom group, there were 5 men and 17 women. Twenty of the participants were White, and 2 were African American. In the high ADHD symptom group, there were 5 men and 15 women. Fifteen of the participants were White, 2 were African American, and 3 were Hispanic. Two of these participants reported taking prescription medication for the treatment of ADHD. Based on self-reported estimates from our previous study, participants in the low group had a mean of 2.92 years of driving experience (SD = 1.20) and drove an average of 6,534 miles per year (SD = 5763). Participants in the high group had a mean of 2.72 years of driving experience (SD = 0.55) and drove an average of 8,982 miles per year (SD = 7182). There were no significant group differences in age, years of driving history, or miles per year driven at the time of the previous study (p > .05).

Apparatus

The electrocardiograms (ECGs) and impedance cardiograms (ICGs) were obtained from a beta version Bionex impedance cardiograph using Mindware Acquisition (Mindware Technologies, Inc., Ver. 2.0, Gahanna, OH) data acquisition system. Five TraceRite silver chloride electrodes were used to obtain the ECGs and ICGs. For ECGs, one spot electrode was placed approximately 5 cm to the left of the suprasternal notch on the participant's collarbone with two electrodes placed over the fifth intercostal space on the participant's left and right thorax. For ICGs, voltage electrodes were placed just below the suprasternal notch, and the xiphoid process and current electrodes were placed on the back approximately 3 to 4 cm above and below the voltage electrodes, respectively. A desktop DriveSafety driving simulator running HyperDrive software (Ver. 1.9.35) was used to present the driving tasks.

Questionnaires

Questionnaires were selected to assess attention disorder symptoms and negative emotions, and were organized into the following categories: (a) ADHD diagnostic scales, which served as the independent variable, and (b) negative emotion measures, which served as dependent variables.

ADHD Diagnostic Scale—The Current Symptoms Scale (Barkley & Murphy, 1998) consisted of two parts that asked participants to describe their behavior during the past 6 months. Part 1 was an 18-item scale that identified the presence of ADHD symptoms in adults and had questions related to inattention (ADHD-I) and to hyperactivity (ADHD-H). Part 2 was a 10-item scale that assessed the extent to which ADHD symptoms interferes with the participants' ability to function in life activities (the impact of attention disorder symptoms). As noted above, it was used to select participants from Time 1 to participate in the present study. However, it was administered again at Time 2 to verify the stability of the classification of participants as having low or high ADHD symptoms in the present study. All participants still met their initial classification criteria as having either low or high ADHD symptoms. The Time 2 measures were used in the analyses for this report.

All items were rated on a 4-point scale (O = *not at all*, 3 = *very much so*) and were scored by counting the number of items that were answered 2 (*often*) or 3 (*very much so*) following *DSM-IV-TR* (APA, 2000) for questions related to either inattention or hyperactivity. According to Barkley and Murphy (1998), participants reporting 2 (*often*) or 3 (*very much so*) for six or more items from either the Inattention or Hyperactivity subscales of the Current Symptoms Scale can be considered "consistent with the presence" of ADHD and warrant further clinical evaluation. Cronbach's alpha for the inattention and hyperactivity measures in the present study were .84 and .82, respectively.

Negative emotion measures—The 61-item Driving Anger Expression Inventory was used to ask participants to indicate how often they generally react or how they behave when they are angry while driving (Deffenbacher, Lynch, Oetting, & Swaim, 2002). All items were rated on a 4-point scale ranging from 1 (*almost never*) to 4 (*almost always*). Angry expressions can be divided into five subscales; however, for the present study, the subscales were added for a total score, with higher scores indicating more driving anger. Coefficient alpha was .80 in the present sample.

The 65-item Driver's Angry Thoughts Questionnaire was used to identify self-reported driving-related angry thoughts and how often participants have these thoughts when they are angry while driving (Deffenbacher, Petrilli, Lynch, Oetting, & Swaim, 2003). Items were rated on a 5-point scale ranging from 1 (*not at all*) to 4 (*all the time*). Angry thoughts (note these are distinct from expressions, in the above paragraph) also can be divided into five subscales; however, for the present study, they were summed to create a total score, with higher scores indicating more angry thoughts while driving. Coefficient alpha was .82 in the present sample.

The NASA Task Load Index (NASA-TLX) is a self-report rating scale of perceived mental workload (Hart & Staveland, 1988) with mental demand, physical demand, temporal demand, effort, performance, and frustration subscales. Although participants rated all scales, we only examined the frustration subscale to verify that simulated driving elicited frustration. Participants rated their perceived levels for each subscale on a scale from 0 to 100. Thus, data from the NASA-TLX served two purposes: (a) They masked our interest in frustration within the mental workload measure as a manipulation check that the simulated driving task elicited frustration as intended and (b) they allowed us to use the frustration subscale as a dependent variable for negative emotions to see if any group differences existed after simulated driving. Overall, test–retest reliability for the NASA-TLX was .80.

Driving Task

The driving task had three conditions: practice, baseline, and frustration. In the practice condition, participants drove a closed circuit route through rural, urban, industrial, and residential streets. No traffic was present in this condition. The purpose of this condition was to get participants acclimated to the driving simulator as well as to the types of road conditions that they would see in subsequent conditions. The mean time to complete the practice condition was approximately 4 min.

The baseline driving condition also included rural, urban, industrial, and residential streets in a closed circuit route; however, this condition contained ambient traffic and the inclusion of parked cars and other features (pedestrians, bicycles, etc.) to mimic more realistic driving conditions. The frustration driving condition was identical to the baseline driving condition with the exception of having heavier ambient traffic and three triggered events intended to provoke frustration while driving. The first event was a car that was parked on the street suddenly pulling out in front of the participant with very little headway (this same car remained parked and stationary in the baseline driving condition). The second event was a signal light (which remained green in the baseline driving condition) turning red as the participant approached, requiring him or her to choose between stopping or running the red light. The third event involved a dump truck (which was parked and stationary in the baseline driving condition) slowly pulling out in front of the participant's vehicle in a construction zone. In addition to these frustration-provoking events, participants were told prior to starting the frustration condition that if they completed the scenario in a faster time than in the baseline driving condition, they would receive an additional US$5.00 in compensation. This motivator was included to elicit frustration while driving as well as to distinguish this task from the baseline driving condition.

Procedure

On arrival, participants provided written informed consent prior to the start of data collection. Subsequently, they were led to the preparation room to affix the electrodes. Participants entered a laboratory room and sat in front of a computer screen with instructions on how to complete the questionnaires. The order of questionnaires was counterbalanced across the participants according to class (i.e., attention disorder symptoms and driving anger) to ensure that the participants were not all exposed to the same order of the questionnaires. After the completion of the questionnaires, participants were moved to another room for the presentation of the driving simulator tasks. Physiological data were recorded while participants completed the practice drive. On completion, they were given the first of three administrations of the NASA-TLX to measure subjective workload (only 30 participants completed the NASA-TLX because the measure was added when the study was in progress). After completing the NASA-TLX, the participants received the following instructions related to the baseline driving condition: “ You are to drive through the scene observing all traffic laws, including speed limits, stop signs, and stoplights without making errors”.

On completion, the participants were told their time to complete the circuit and then completed the second administration of the NASA-TLX. After completing the NASA-TLX, the participants received the following instructions related to the frustration driving condition: “You will drive the scene again and will receive an extra US$5.00 if you beat your previous time. Observe all traffic laws, including speed limits, stop signs, and lights without making errors.”

Physiological data were recorded while participants completed both driving tasks. Participants completed the last administration of the NASA-TLX, and received debriefing information and US$15.00 compensation for their time (no participant completed the frustration driving condition in less time than the baseline driving condition).

Data Quantification

Physiological data—ECGs and ICGs were used to obtain noninvasive indices of cardiac sympathetic and parasympathetic nervous system activity (Cacioppo et al., 1994). All physiological measures were collected at a rate of 1000 Hz. We used heart period as the end organ measure of cardiac activity rather than heart rate because of its superior biometric properties (Berntson, Cacioppo, & Quigley, 1995). Heart period was calculated as the mean time in ms between successive R-peaks of the ECG, so that an increase in heart rate results in shortening of heart period. Respiratory sinus arrhythmia (RSA: the parasympathetic index) refers to variations in heart rate that are related to respiratory modulation of the outflow of the vagus nerve (Berntson et al., 1997) and was calculated as the natural logarithm of the power in the high-frequency heart period variability frequency band (0.12-0.40 Hz) by applying fast Fourier transform (FFT) to the resampled R-R intervals.

Mindware HRV (Ver. 2.2., Mindware Technologies, Inc.) was used to determine heart period and RSA over 60-s epochs. Each epoch was free from artifact.

Preejection period (PEP: the sympathetic index) is the systolic time interval between the onset of ventricular depolarization (i.e., the trough of the Q wave) and the onset of left ventricular ejection of blood flow into the aorta (the B-point of the dZ/dt). We calculated the B-point as 56% of the time (in ms) between the trough of the Q wave and the Z-point of the ensemble averaged dZ/dt waveform (Berntson, Quigley, & Lozano, 2007; Lozano et al., 2007). Mindware IMP (Ver. 2.2., Mindware Technologies, Inc.) was used to screen for artifact over 60-s epochs prior to scoring. Respiration rate (breaths/minute) and respiration amplitude (in arbitrary units) were collected as control measures to aid in the interpretation of RSA and were obtained from the ICG pneumography data (Ernst, Litvack, Lozano, Cacioppo, & Berntson, 1999).

Resting baseline physiological data were collected for 2 min prior to the administration of each of the driving conditions (i.e., practice, baseline, and frustration). Resting baseline consisted of 1 min of recovery time followed by 1 min of resting baseline that was used for data analysis. A mean resting baseline was calculated using the three resting baseline conditions.

Reactivity scores were calculated as the change between the score for a measure in an experimental condition and the mean resting baseline score for that condition. Positive reactivity scores indicate an increase in the measure from baseline to condition, whereas negative scores indicate a decrease in the measure from baseline to condition. Positive scores in heart period reflect longer interbeat intervals (or slower heart rates). Positive RSA scores indicate greater parasympathetic activation. Positive (i.e., longer) PEP scores reflect weaker sympathetic control and is a primary indicator of sympathetic withdrawal. Positive respiration and amplitude scores reflect faster and deeper breaths. Negative reactivity scores from the task condition to resting baseline in heart period, RSA, PEP, respiration rate, and amplitude reflect increased heart rates, parasympathetic withdrawal, sympathetic activation, and slower and shallower breathing, respectively.

Driving task—Performance measures collected during simulated driving were the root mean square of lateral deviation (RMSld) between the center of the participant’s vehicle and the center of the lane (in m), the average velocity (in km/hr), and the standard deviation of the steering wheel angle (arbitrary units). All driving performance measures were collected at a rate of 60 Hz. In addition, the number of hazardous errors made (i.e., collisions, lane excursions, and speeding) were also recorded over the entire scenario. To examine the effects of frustration on participant driving behavior, we compared behaviors that occurred at similar locations in both scenarios. The frustration condition included three events that were designed to elicit frustration that mimicked real-world events: vehicle intrusion, stoplight, and construction. For the stoplight event, driving performance was confounded by whether participants stopped or failed to stop at the light in the frustration condition. The red-light duration occurred for 45 s within the 60 s segment. Thus, performance and physiological data for the stop light event were confounded by those participants who failed to stop at the light. Therefore, we only examined discrete behavior for this event (i.e., those who stopped at the light vs. those who failed to stop at the light). The locations of the remaining events were marked, and the driving behavior and physiological reactivity 60 s after the events were compared with identical segments from the baseline driving condition. However, no physiological data were collected for 8 participants (3 from the low ADHD symptom group and 5 from the high ADHD symptom group) because of equipment failure.

Results

The present study examined the following questions: (a) Are there group differences in self-reported negative emotions? (b) Are there group differences at the tactical level of driving performance? and (c) If group differences exist in driving performance, are those differences associated with reduced physiological activity and/or with some other factor such as inattention or the presence of negative emotions?

Manipulation Checks

To confirm the classification of participants into high and low ADHD symptom groups, we examined the scores on the Current Symptoms Scale at Time 2. As expected, there were still significant differences in ADHD symptoms between groups (see Table 1), and there were no changes in the initial classification of participants into high and low symptom groups. Therefore, we concluded that participants in the high ADHD symptom group continued to represent a high attention-problems group.

As stated earlier, the first purpose of the NASA-TLX was to mask frustration within the mental workload measure to verify whether the driving conditions varied as intended with regard to perceptions of frustration. Responses on the frustration subscale were examined using a 2 (group) × 2 (condition: baseline driving vs. frustration driving) ANOVA to determine if there were significant condition effects. As expected, there was a significant main effect of condition on the frustration subscale, $F(1, 28) = 47.21$, $p < .01$ (baseline driving: $M = 34.51$, $SD = 23.99$; frustration driving: $M = 61.80$, $SD = 23.44$), and no interaction between group and condition. Participants reported higher perceptions of frustration during the frustration driving condition than during the baseline driving condition, which confirmed that the two driving conditions differed as intended.

Group Differences in Self-Reported Negative Emotions

Table 1 summarizes the results for the measures of driving anger. Although there were no significant group differences in angry *thoughts* (Driver's Angry Thoughts Questionnaire, $p = .12$), group differences appeared for the *expression* of anger (Driving Anger Expression Inventory, $p < .01$). This picture supports the supposition that individuals with ADHD did not have more angry thoughts but were expressing more of the anger they did have, partly supporting our hypothesis. Participants with high ADHD symptoms reported significantly higher expressions of anger that were tied into the actual experience of driving. As shown in Table 1, responses on the NASA-TLX frustration scale were examined to determine if significant group differences existed in frustration levels after driving the baseline driving and frustration driving conditions. As expected, the high ADHD symptom group had significantly higher frustration than did the low ADHD symptom group in the frustration condition; in addition, they also had significantly higher frustration in the baseline driving condition.

Group Differences in Simulated Driving Performance

Performance 60 s after passing the trigger point for the frustration-provoking events (intrusion and construction events) in the baseline driving and frustration driving conditions was examined using a 2 (group: low vs. high) × 2 (condition: baseline driving vs. frustration driving) ANOVA. Participants from both groups demonstrated similar operational driving skills (i.e., lane deviation, average velocity, and steering) for each event. As expected, there were no significant group differences or Group × Condition interactions found for any of the operational driving skill measures for either the intrusion or construction events.

For the intrusion event, there was a significant main effect of condition on RMS lane deviation, mean velocity, and standard deviation of the steering wheel angle (see Table 2). In the frustration condition, all participants deviated less from the lane center, demonstrated more steering control, and drove slower than in the baseline driving condition because of the unexpected entry of the parked car onto the road. For the construction event, there was also a significant main effect of condition on RMS lane deviation, mean velocity, and standard deviation of the steering wheel angle. In the frustration condition, participants from both groups deviated more from the lane center, drove faster, and steered more than in the baseline driving condition because of the merge of the slow-moving truck in the construction zone.

Although participants in both groups demonstrated similar operational driving skills, participants in the high ADHD symptom group committed significantly more maladaptive driving errors (related to tactical driving skills) than participants in the low ADHD symptom group, confirming our hypothesis. For example, participants in the high ADHD group had significantly more collisions than did participants in the low, ADHD, group, $\chi^2(1, N = 42) = 3.84$, $p < .05$. Moreover, the number of participants with multiple collisions (>1) was significantly greater for participants in the high ADHD symptom group than for participants in the low ADHD symptom group, $\chi^2(1, N = 42) = 7.82$, $p < .01$. In addition, a significantly higher number of participants in the high ADHD symptom group failed to stop at the light in the frustration condition than did participants in the low ADHD symptom group, $\chi^2(1, N = 42) = 9.45$, $p < .01$.

Factors Influencing Simulated Driving Performance Differences

Like Iaboni et al. (1997) found for children, there were no significant differences in resting baseline scores between the high and low ADHD symptom groups (Table 3). As shown in Table 4, mean reactivity scores for physiological measures were calculated for the baseline driving and frustration driving conditions. The effects of group and condition on physiological reactivity scores for the 60-s segment after the frustration-provoking events (intrusion and construction events) were examined using a 2 (group) × 2 (condition) ANOVA on each dependent variable. Contrary to our hypothesis, there were no significant main effects or interactions, but we examined the intercept of the ANOVAs to determine if there were significant reactivity differences in physiological measures from resting baseline.

The following intercepts were significant. For the intrusion event, the intercepts for RSA, $F(1, 32) = 24.57$, $p < .01$, and respiration rate, $F(1, 32) = 27.03$, $p < .01$, were significantly different from zero. For the construction event, the intercepts for RSA, $F(1, 32) = 26.74$, $p < .01$, respiration rate, $F(1, 32) = 8.36$, $p < .01$, and respiration amplitude, $F(1, 32) = 5.95$, $p < .05$, significantly differed from zero. Follow-up, single-sample *t* tests were performed for those variables that had significant intercepts (see Table 4). All participants had decreased vagal activity from resting baseline to both driving conditions for both events. Moreover, all participants breathed faster than during resting baseline. Although there was significant cardiorespiratory reactivity during the driving tasks, reactivity did not differ between groups.

We further examined tactical driving performance to determine whether the observed maladaptive behaviors for the high symptom group were due to the symptom domains of the disorder (i.e., inattention, hyperactivity/impulsivity) or due to the presence of negative emotions. We discovered that not all drivers within the high ADHD symptom group committed tactical errors during simulated driving. There was a subgroup of participants within the high group who had significantly higher maladaptive errors than their counterparts. Therefore, we conducted univariate ANOVA on the total scores from the Current Symptoms Scale, the Driving Anger Expression Inventory, and the frustration subscale of the NASA-TLX across three groups: (a) participants with low ADHD symptoms without multiple collisions ($n = 21$), (b) participants with high ADHD symptoms but without multiple collisions ($n = 12$), and (c) participants with high ADHD symptoms and with multiple collisions ($n = 8$).

Significant group differences existed on total scores of the Current Symptoms Scale, the Driving Anger Expression Inventory, and the baseline and frustration driving conditions of the NASA-TLX (see Table 5). Follow-up analyses on the subscales of the Current Symptoms Scale showed that the symptom scores for the subgroup of participants in the high symptom group who made tactical errors was higher than those who did not; however, the symptom scores were not significantly higher. Neither the total score nor scores on the individual symptom domains distinguished the participants in the high symptom group who committed maladaptive driving errors from those who did not.

However, the subgroup of participants with high ADHD symptoms who had more tactical errors reported that they were significantly more likely to express anger while driving (see Table 5). Examination of the Driving Anger Expression Inventory showed that participants in the low symptom group significantly differed from participants in the high symptom group with multiple collisions, but the high symptom group without multiple collisions did not differ from either of the other groups. Furthermore, participants from the high symptom group with multiple collisions reported significantly higher levels of frustration on the NASA-TLX than participants from the low and high symptom groups without multiple collisions. Moreover, even during the baseline driving condition, where no frustration events occur, the high symptom subgroup with multiple collisions reported that they were significantly more frustrated than the other two groups. Although participants from the high symptom group have similar expression of ADHD symptoms, there is a subgroup within the high symptom group that experiences significantly higher levels of negative emotions.

Thus, our hypothesis regarding the impact of negative emotions on simulated driving performance for participants with high ADHD symptoms was confirmed. The observed differences in maladaptive driving behaviors (related to tactical driving skills) performed by a subgroup of participants with high ADHD symptoms appeared to be due to the presence of frustration and negative emotions and not due simply to the presence of attention disorder symptoms.

Discussion

A significant percentage of children with ADHD experience symptoms that persist into adulthood (Barkley, 1998). One characteristic of young adults with ADHD is that they have a higher incidence of maladaptive driving behavior than their peers without ADHD (Barkley, 2004; Richards et al., 2002). The first purpose of this study was to examine whether there were differences in simulated driving performance between groups with high and low levels of attention disorder symptoms and, if so, whether the differences were at the operational and/or tactical level of driving performance.

In the current study, participants in the high ADHD symptom group did not differ from the low ADHD symptom group on operational measures of simulated driving performance such as steering, maintaining speed, and lane position. Instead, the high symptom group showed the predicted pattern of more tactical errors, such as running a red light and having multiple collisions, than did the low symptom group. Overall, these results are similar to Barkley (2004) and Richards et al.'s (2002) results that found highly symptomatic ADHD individuals are more likely to commit hazardous errors while driving (i.e., run red lights and experience greater numbers of crashes).

We believe that these results support both the use of driving simulation and a college sample to study maladaptive driving in young adults with attention disorders. The participants in our high ADHD symptom group had high test–retest correlations on attention disorder measures, which showed that participants who exhibited symptoms of ADHD at the time of the previous study conducted more than 1 year before the current study still met diagnostic criteria for inattention and hyperactivity. However, they did not report that their symptoms had an impact on daily functions and in fact were high-functioning individuals who had successfully completed at least their freshman year of college at the time of this study. Although we had a group with stable elevated ADHD symptoms, some members would likely not meet formal criteria for ADHD, according to the APA (2000). Even so, the maladaptive driving behavior evidenced by the high ADHD symptom group in our simulation study closely matched the behavior reported in the literature on the driving records of adult ADHD clinical samples.

The second purpose of this study was to determine whether the high and low ADHD symptoms groups differed in negative affect related to driving. According to Ramirez et al. (1997), individuals with ADHD have higher levels of negative emotions than their non-ADHD counterparts. These higher levels of negative emotions put them at an increased risk for adverse driving outcomes under frustrating conditions or during scenarios where they feel provoked. In addition, Ross, Harris, Olincy, and Radant (2000) found that individuals with ADHD demonstrate disinhibition as well as difficulty suppressing unwanted motor responses (“effortful motor inhibition”; Nigg, Butler, Huang-Pollock, & Henderson, 2002), both of which have serious implications for driving safety.

Our results showed that individuals with high attention disorder symptoms do report increased frustration and anger when driving, which when provoked results in verbally and physically aggressive behaviors, although they do not report having more angry thoughts than the low ADHD symptom group. The discrepancy between the two measures of driving anger may be because participants found it easier to recall and/or rate their actions rather than their thoughts. According to Galovski, Malta, and Blanchard (2006), both anger (an emotional state) and hostility (cognition/angry thoughts) contribute to and may promote aggressive driving. Left unchecked, aggressive driving can lead to incidences of road rage, where motorists lose their temper in reaction to various traffic scenarios (i.e., slow drivers in a fast lane, someone tailgating, or being cut off by other drivers) and potentially use their vehicles to make sudden threatening maneuvers on the road (AAA Foundation for Traffic Safety, 2009). The current study suggests that driving anger may be more important than hostility for young adults with attention disorder symptoms, but there clearly needs to be more research that looks at these constructs separately before definitive conclusions can be made. Nonetheless, participants with high attention disorder symptoms did report significantly higher frustration levels while driving, which lends additional support to our hypothesis regarding the presence of negative emotions for the high ADHD symptom group.

Having found that the high ADHD symptom groups had more tactical driving errors and report more negative emotions than the low ADHD group, we could then examine the third purpose of the current study. We wanted to determine whether self-reported negative emotions and cardiorespiratory reactivity and/or the two symptom domains of ADHD better accounted for the tactical driving errors during simulated driving performance under frustrating conditions. Our approach to this question was to form subgroups of low ADHD symptom participants without multiple collisions, high ADHD symptom participants without multiple collisions, and high ADHD symptom participants with multiple collisions during the frustration scenario, and then to use these subgroups to look at the ADHD Current Symptom Scales, the Driving Anger Expression Inventory, and the NASA-TLX Frustration measure.

The results of this analysis (reported in Table 5) clearly show that the subgroup of high ADHD symptom participants with multiple collisions differ from the high ADHD symptom participants without multiple collisions primarily in the intensity of their negative emotions. In fact, the high ADHD symptom group without multiple collisions does not differ from the low ADHD symptom group for the frustration measure that was taken immediately following the baseline and frustration driving scenarios. However, the high symptom group reported significantly more frustration than the other two groups, even during the baseline drive that did not have any frustrating events. Although the subgroup analysis in Table 5 indicates that the two high symptom groups do not differ in the severity of their attention disorder symptoms, it must be remembered that the individuals within this group were selected because they had a high score on the Current Symptom Scale at Time 1 when they participated (Oliver, 2007). However, the current findings support (Oliver, 2007) in that we found that the presence of high negative emotions seems to better account for maladaptive driving behavior in young adults than does the mere presence of attention disorder symptoms.

For the cardiorespiratory measures, we found that there were no physiological resting baseline differences between the low and high ADHD symptom groups, like Iaboni et al. (1997) found for children. Although we found significant suppression of vagal activity as measured by RSA during simulated driving, there were no significant group differences in cardiorespiratory reactivity during either the baseline or frustration driving conditions. Unfortunately, the loss of data due to equipment failure prevented us from examining the physiological data for the subgroup analysis, so the question of whether cardiorespiratory reactivity is associated with tactical driving errors made during frustrating conditions still needs to be answered.

These results should be interpreted in light of several limitations of the study. First, the small number of participants led to low statistical power for the analyses. The sample was additionally restricted for the physiological measures due to equipment failure for some of the participants, although there were still significant cardiorespiratory differences from baseline to task conditions. However, this loss of participants meant that we could not examine the physiological data for the subgroups of the high ADHD group with and without multiple collisions. Second, although this sample was more heterogeneous compared with the previous study (Oliver, 2007), the sample was still predominantly female and White. As there are gender differences in cardiac reactivity (Beauchaine, Hong, & Marsh, 2008), a more diverse sample would positively effect external validity and allow generalizability to a broader population. Third, the use of rewards in the Iaboni et al. (1997) study resulted in significant physiological differences between ADHD and non-ADHD children. Perhaps, the inclusion of a larger reward in the driving task would have led to significant between-group differences in the physiological data. Last, it appears that the key factor in the occurrence of maladaptive driving behaviors for some participants with high ADHD symptoms is not due to the presence of inattention or hyperactivity but due to the presence of negative emotions. However, maladaptive errors, such as running a red light, may be due to those participants having impaired decision-making skills (see Fischer, Barkley, Smallish, & Fletcher, 2007). Although decision making was not assessed in the present study, it is a factor that will be explored in the future. Nonetheless, our data are sufficiently novel and have important implications for designing effective training programs for individuals with ADHD.

Conclusion

We did observe group differences in simulated driving performance during frustrating driving conditions that mirrored the literature for on-road driving. Researchers propose that ADHD drivers should “receive more extensive training in sound driving practices” (Barkley, Murphy, & Kwasnik, 1996, p. 1094). However, in light of the current findings, we propose that training for this population should focus more on the emotional state of the individual rather than on their basic driving skills. Drivers with higher levels of ADHD symptoms report more anger during driving, and those who report the highest levels of driving anger and frustration have the most serious driving problems. Therefore, remedial training regimens should be designed to include strategies that address anger and control of negative emotions as opposed to those that solely address attention ability or driving skills (Oliver, 2007). Future studies will examine what we need to remediate in driving programs. However, in terms of driving safety, our analysis examining subgroups of ADHD drivers show that emotion-regulation problems may be more impairing than inattention symptoms for drivers with ADHD. If successful, recurrent emotion control training may help encourage drivers with ADHD to learn and maintain high levels of driving performance and safety at the same levels as non-ADHD drivers.

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Biographies

Michele L. Oliver received her BS from Polytechnic University and her MS from Central Michigan University, where she is a doctoral candidate in the Applied Experimental Psychology Program.

Joel T. Nigg, PhD, is a professor of psychiatry and behavioral neuroscience at Oregon Health & Science University.

Nicholas D. Cassavaugh, received his PhD from the University of Illinois at Urbana–Champaign in 2007 and has been at Central Michigan University since January of that year. He is presently the assistant director of the Center for Driving Evaluation, Education and Research at Central Michigan University.

Richard W. Backs, PhD, is a professor of psychology and director of the Center for Driving Evaluation, Education and Research at Central Michigan University.

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Table 1

ANOVA of Self-Reported Questionnaires for Low (n = 22) and High (n = 20) ADHD Symptom Groups

	Low group	High group	
Questionnaire	***M* (*SD*)**	***M* (*SD*)**	**F(1, 40)**
ADHD Current Symptoms Scales (T1)[a]	6.68 (4.31)	18.60 (5.22)	65.59**
ADHD Current Symptoms Scales (T2)[b]	8.23 (4.75)	16.35 (6.55)	21.46**
Driver's Angry Thoughts Questionnaire	139.23 (27.49)	153.25 (29.61)	2.53
Driving Anger Expression Inventory	84.68 (11.87)	97.40 (13.67)	10.41**
NASA-TLX baseline drive[c]	28.21 (12.01)	40.81 (30.73)	4.20*
NASA-TLX frustration drive[c]	52.79 (21.20)	70.81 (25.13)	4.44*

Note: NASA-TLX = NASA Task Load Index.

[a]The ADHD Current Symptoms Scale (T1) was administered at the time of the previous study (Oliver, 2007).

[b]The ADHD Current Symptoms Scale (T2) was administered during the present study as a manipulation check that participants still met the initial classification of being in either the high or low ADHD symptom group.

[c]n = 14, n = 16 (for low and high groups, respectively) for the NASA-TLX because the measure was added when the study was already in progress.

*$p < .05$.

**$p < .01$.

Table 2

Means (and Standard Deviations) of Operational Driving Performance for the 60-s Segment After the Intrusion and Construction Events and Frequency of Tactical Driving Performance Errors for Low and High ADHD Symptom Groups

			Baseline driving condition		Frustration driving condition	
	Event	Variable	Low	High	Low	High
Operational skills	Intrusion	RMS lane deviation (m)[a]	0.43 (0.12)	0.40 (0.15)	0.30 (0.14)	0.27 (0.11)
		Average velocity (km/hr)[a]	47.29 (10.92)	49.90 (11.54)	36.29 (5.68)	38.78 (9.76)
		SD of steering wheel angle[a] (arbitrary units)	28.83 (22.38)	25.30 (15.16)	4.52 (3.36)	6.11 (11.51)
	Construction	RMS lane deviation (m)[a]	0.31 (0.10)	0.35 (0.13)	0.52 (0.17)	0.54 (0.19)
		Average velocity (km/hr)[a]	42.03 (10.86)	42.24 (10.79)	60.36 (16.87)	62.92 (19.10)
		SD of steering wheel angle[a] (arbitrary units)	3.37 (3.51)	2.78 (2.92)	16.24 (9.61)	16.24 (7.61)
Tactical skills	Stoplight	Number of participants who went through the red stop light in the frustration trial	—	—	1	9**
	Entire scenario	Total number of collisions	5	1	14	29*
		Total number of participants experiencing multiple (>1) collisions	2	0	1	8**

Note: RMS = root mean squared. Low ADHD symptom groups: $n = 22$, and high ADHD symptom groups: $n = 20$.

[a]Indicates significant condition effects existing between the baseline and frustration driving conditions ($p < .01$).

*$p < .05$.

**$p < .01$.

Table 3

Means (and Standard Deviations) for Resting Baseline Reactivity Scores for Low (*n* = 22) and High (*n* = 20) ADHD Symptom Groups

	Mean driving baselines			
Variable	**Low group**	**High group**	***t***	***p***
Heart period (ms)	770 (79)	804 (180)	−0.80	.43
RSA (ln[ms^2])	6.62 (0.89)	6.54 (0.96)	0.26	.79
PEP (ms)	117 (12)	116 (16)	0.30	.77
Respiration rate (breaths/min)	15.01 (2.45)	15.23 (2.22)	−0.31	.76
Respiration amplitude (arbitrary units)	0.34 (0.68)	0.18 (0.25)	0.99	.33

Note: RSA = respiratory sinus arrhythmia; PEP = preejection period.

Table 4

Means (and Standard Deviations) for Cardiovascular Reactivity Scores for the 60-s Segment After the Intrusion Construction Events for the Low and High ADHD Symptom Groups and Construction Events for the Low and High ADHD Symptom Groups

			Baseline driving condition		Frustration driving condition	
Event	**Variable**	**Intercept**[a]	**Low group**	**High group**	**Low group**	**High group**
Intrusion	Heart period (ms)	5 (37)	4 (36)	1 (50)	7 (27)	7 (49)
	RSA (ln[ms^2])	−0.47** (0.55)	−0.52** (0.74)	−0.51* (0.69)	−0.42** (0.48)	−0.44* (0.60)
	PEP (ms)	−2 (8)	0.5 (8)	−1 (6)	−1 (14)	−4 (7)
	Respiration rate (breaths/min)	2.87** (3.22)	4.30** (3.43)	0.96 (4.15)	3.19** (3.24)	3.03* (5.19)
	Respiration amplitude (arbitrary units)	−0.05 (0.59)	0.22 (1.67)	−0.11 (0.24)	−0.15 (0.50)	−0.14 (0.24)
Construction	Heart period (ms)	−4 (32)	−16 (38)	−2 (36)	11 (36)	−7 (46)
	RSA (ln[ms^2])	−0.57** (0.65)	−0.48* (0.90)	−0.64** (0.65)	−0.49* (0.86)	−0.69** (0.82)
	PEP (ms)	−1 (7)	1 (6)	−1 (6)	−1 (8)	−3 (8)
	Respiration rate (breaths/min)	1.80** (3.64)	3.09** (3.29)	0.48 (4.44)	2.46* (4.66)	1.18 (5.27)
	Respiration amplitude (arbitrary units)	−0.22* (0.53)	−0.28 (0.61)	−0.17* (0.28)	−0.25 (0.73)	−0.18* (0.27)

Note: RSA = respiratory sinus arrhythmia; PEP = preejection period. Low ADHD symptom groups: n = 19 and high ADHD symptom groups: n = 15. An asterisk notation for the baseline and frustration driving conditions denotes the results of follow-up t tests, which revealed under which conditions, and for which groups, reactivity scores differed from zero.

[a] The intercepts of a 2 (group) × 2 (condition) ANOVA show the variables that were significantly different from zero, indicating that these physiological measures were significantly different from resting baseline.

* $p < .05$.

** $p < .01$.

Table 5

Means (and Standard Deviations) for the Current Symptoms Scale, the Driving Anger Expression Inventory, and the NASA-TLX Frustration Scale

	Low group without multiple collisions (*n* = 21)	**High group without multiple collisions (*n* = 12)**	**High group with multiple collisions (*n* = 8)**	
Questionnaire	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**	**F(2, 38)**
Current Symptom Scale	8.43[a] (4.77)	15.50[b] (5.40)	17.63[b] (8.21)	10.12**
Inattention	3.52[a] (2.36)	7.50[b] (2.88)	8.38[b] (3.78)	12.29**
Hyperactivity	4.90[a] (2.96)	8.00[b] (2.86)	9.25[b] (4.83)	6.19**
Driving Anger Expression Inventory	84.24[a] (11.98)	95.50[a,b] (13.20)	100.25[b] (14.75)	5.67**
NASA-TLX frustration (Baseline drive)	28.92[a] (12.20)	27.80[a] (28.89)	62.50[b] (20.68)	6.29**
NASA-TLX frustration (Frustration drive)	51.62[a] (21.59)	59.60[a] (25.69)	89.50[b] (6.02)	6.65**

Note: NASA-TLX = NASA Task Load Index. For the NASA-TLX, $n = 14$ for controls, $n = 8$ for participants with high ADHD symptoms without multiple collisions, and $n = 8$ for participants with high ADHD symptoms with multiple collisions. Superscripts were used to indicate whether significant group differences existed. Similar superscripts indicate that no significant differences existed. Different superscripts indicate that significant group differences existed on post hoc tests using Tukey paired comparisons ($p < .05$).

** $p < .01$.