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Association between Executive Function and Problematic Adolescent Driving

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Abstract

Objective—Motor vehicle collisions (MVCs) are one of the leading causes of injury and death for adolescents. Driving is a complex activity that is highly reliant on executive function to safely navigate through the environment. Little research has examined the efficacy of using self-reported executive function measures for assessing adolescent driving risk. This study examined the Behavior Rating Inventory of Executive Function (BRIEF) questionnaire and performance based-executive function tasks as potential predictors of problematic driving outcomes in adolescents.

Methods—Forty-six adolescent drivers completed the (1) BRIEF, (2) Trail Making Test (TMT), (3) Backwards Digit Span, and (4) self-report on three problematic driving outcomes: the number of times of having been *pulled over* by a police officer, the number of *tickets* issued, and the number of *MVCs*.

Results—Greater self-reported difficulty with planning and organization was associated with greater odds of having a MVC, while inhibition difficulties were associated with greater odds of receiving a ticket. Greater self-reported difficulty across multiple BRIEF subscales was associated with greater odds of being pulled over.

Conclusion—Overall findings indicated that the BRIEF, an ecological measure of executive function, showed significant association with self-reported problematic driving outcomes in adolescents. No relationship was found between performance-based executive function measures and self-reported driving outcomes. The BRIEF could offer unique and quick insight into problematic driving behavior and potentially be an indicator of driving risk in adolescent drivers during clinical evaluations.

Keywords

Adolescent; Executive Function; Driving; Problematic Driving Outcomes; Injury Prevention

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Motor vehicle collisions (MVCs) are one of the leading causes of injury and death for adolescents in the United States.¹ Driving is a complex activity performed within a dynamic environment that is highly reliant on cognitive function.^{2,3} Executive function is one such cognitive ability that involves higher level management of a broad set of processes including working memory, problem solving, planning prospective actions, attention, and multitasking.⁴ Different from the developmental trajectories of sensory and motor areas, which are fully developed after the first few years of life, executive function cognitive processes and their related brain structures continue to develop past adolescence.^{5,6}

Poorer executive function has repeatedly been connected with negative driving outcomes in older adults and clinical populations; however, this relationship has not been well investigated in adolescent drivers^{2,3,7} despite continued brain development beyond adolescence.⁸ Traditionally, executive function has been assessed through performance-based tasks, which involve using standardized assessments of specific cognitive processes or domains.² Risky behaviors in adolescents, such as fighting, acting without thinking, and engagement in risky behavior, have been negatively associated with performance-based executive function domains including working memory and decision-making abilities.^{6,9,10} Related to driving, Mäntylä, Karlsson, Marklund² found that poor performance on updating tasks (i.e. working memory tasks), but not shifting or inhibition measures, predicted poor simulated driving performance in healthy, adolescent drivers. Ross, Jongen, Brijs, Ruiter, Brijs, Wets¹¹ found that poor performance on inhibitory control and working memory measures, such as the cued go-no-go task and backwards digit span, predicted more variability in lane position using a driving simulator. Decreased response inhibition was also predictive of more collisions and longer responses to hazards in the driving simulator. However, contrary to the pattern of poorer cognition predicting poorer driving performance, Ross, Jongen, Brijs, Ruiter, Brijs Wets found that better visuospatial working memory performance predicted increases in risky driving behaviors in adolescents, specifically involving running yellow lights and shorter following distances.¹¹ These findings allude to the fact that the relationship between executive function and driving in adolescents is complex and clearly in need of further research.

Adding to the complexity of executive function's role in teen adolescent driving is the variability found in performance-based measures of executive function. Performance-based executive function measures have their own set of limitations, such as varying operational definitions; construct validity and reliability issues, and tedious administration.^{2,4,7} These methodological limitations along with the complexity of the driving environment may contribute to the lack of studies investigating executive function in teen adolescent driving.³ Self-report measures are an alternative and possible supplement to performance-based measures of executive function. These measures are often easy and quick to administer in a clinical setting and generally are ecologically developed to include hypothetical real-world situations.

One such measure, the Behavior Rating Inventory of Executive Function (BRIEF)^{12,13}, includes questions designed to capture behaviors to detect executive difficulties in community-dwelling children and adults.¹⁴ It is easy and quick to administer (approximately 10-15 minutes), with versions available for informant report by parents and teachers. While

considered a measure with ecological validity^{15,16}, use of the BRIEF with clinical populations, e.g., Attention Deficit Hyperactivity Disorder (ADHD), has shown little to no association with traditional validated performance-based executive function measures¹⁷ potentially indicating that it assesses real-life behavioral aspects of executive functioning not captured by traditional performance tests.¹⁷⁻¹⁹

Recently, studies by Rike and colleagues have begun to investigate the relationship between the BRIEF and driving behavior in adult clinical populations^{20,21} who typically demonstrate driving difficulties^{22,23}, such as individuals suffering from stroke or traumatic brain injury. Results revealed no significant difference in overall BRIEF scores and performance-based on-road driving assessment. However, greater perceived cognitive difficulties on the BRIEF indices of behavioral regulation, metacognition, and overall global executive functioning were positively correlated with higher rates of self-reported risky driving.²⁰ It is important to note that these studies were limited to clinical adult populations, possibly limiting generalizability to other driving populations.

The goal of the current study was to assess the relationship between executive function and problematic driving outcomes in adolescents. Specifically, this study sought to determine whether the BRIEF, a self-report measure of executive function-related difficulty, was associated with problematic driving outcomes in adolescents after taking into account the relation with performance-based measures. Due to the multiple components of executive function, the primary aim examined the relationship between individual executive function domains, subcomponents of the self-reported BRIEF, two performance-based executive function measures, and problematic driving outcomes. Based on the established relationship between executive function and driving, it was hypothesized that individual subscales of the BRIEF and the performance-based executive function measures would significantly correlate with self-reported problematic driving outcomes. To our knowledge, the current study is among the first to investigate self-reported executive difficulty in healthy adolescent drivers.

METHODS

Sample

A total of 46 adolescent drivers between the ages of 16 – 19 years ($M_{age} = 17.41$ years, $SD = 1.12$) were recruited as part of a larger driving study (XXX) in XXXXX between December 2013 and July 2014. Participants were recruited through local advertisements, flyers and letters in the community. Eight-six adolescents between the ages of 16 and 22 replied to the recruitment flyers and were initially screened. Due to the nature of the larger naturalistic driving study inclusion criteria for adolescents were: being between the ages of 16 and 19, having a valid driver's license, being the owner and or primary driver of their vehicle, having comprehensive insurance, owning a cell phone with texting capabilities, driving at least 3 times per week, and having a working in-vehicle power outlet. Forty-eight of the interested adolescents met inclusion criteria and were enrolled, consented, and fully participated.

The 38 adolescents not enrolled were excluded for one or more of the following reasons: being younger than 15 or older than 19 years of age ($n = 4$), not having comprehensive driving insurance ($n = 10$), driving less than 3 days per week ($n = 1$), and not having the

required working in-vehicle power outlet ($n = 4$). Furthermore eight failed to show up for scheduled baseline appointments, six opted out due to disinterest, and five were eligible, but screened at the end of the enrollment phase of the study. Of the 48 participants, 4.2% ($n = 2$) did not return at-home questionnaires, resulting in a final sample of 46 adolescents.

The final sample consisted of 58.70% ($n = 27$) women, 69.57% ($n = 32$) Caucasian race, with a current education level of 11.02 years ($SD = 1.45$). Refer to Table 1 for further demographics. Following previous findings from Rike, Ulleberg, Schultheis, Lundqvist, Schanke²⁰ who found moderate correlations between the BRIEF and self-reported driving outcomes, an a-priori power calculation was conducted to determine minimum sample size to achieve adequate power for point-biserial correlations²⁴. To obtain a moderate correlation at 80% power, a minimum of 44 participants was required, making our sample large enough to detect moderate to medium size effects.

Procedure

A university IRB approved all procedures, and in person written consent was obtained from adolescents and guardians. Participants were telephone screened for study eligibility, demographic information, and the lab-generated driving behavior and history questionnaire to assess study inclusion criteria. Participants were mailed questionnaires, including the BRIEF, and asked to complete them at home and return them two weeks later at their in-person visit. All performance-based cognitive measures were conducted during the in-person visit. Because of the short time window between the initial telephone screening and first baseline visit (2 weeks) there were no concerns of major developmental change that could interact with the research question of interest. All participants were monetarily reimbursed 150 dollars for their participation in the larger study.

Measures

Demographics—Age, gender, race, and years of education were self-reported. No differences between races were found on any of the outcome measures, but men were more likely to have reported more incidents of being pulled over, $\chi^2 = (1, N = 46) = 11.64, p = .001$, and receiving a ticket, $\chi^2 = (1, N = 46) = 9.48, p = .002$, than women.

The Behavior Rating Inventory of Executive Function (BRIEF)—This questionnaire is a 75-question (80 questions for BRIEF-SR) paper and pencil assessment of executive function. Two normed versions of the BRIEF were used to accommodate the age ranges of adolescent drivers in the current study (i.e., version SR for ages 11 – 18 and version A for 19 year-olds). Reliability was assessed using Cronbach's alpha with all subscales for the BRIEF-SR having acceptable to good internal consistency (0.75 to 0.98). Due to the small sample for the BRIEF-A ($n = 9$), Cronbach's alphas could not be conducted²⁵, though previous literature has reported high consistent reliability (0.73 - 0.96) across studies for all BRIEF-A scales.^{12-14,16} The two versions of the questionnaire differed slightly, but both versions contained questions pertaining to self-reported executive function behaviors using a three-point scale: never (1), sometimes (2), and often (3). BRIEF questions capture behaviors related to cognitive difficulties such as, “I have trouble with jobs or tasks that have more than one step.”

Additionally, the BRIEF assessed executive function-related behavior across two composites, the Behavioral Regulation Index (BRI) and the Metacognitive Index (MI), which summed to give an overall global score of executive functioning, the Global Executive Composite (GEC) score. The BRI was comprised of four subscales: inhibit, shift, emotional control, and self-monitor (monitor for version SR). The MI was comprised of five subscales: initiate (not included on version SR), working memory, plan/organize, task monitor (task completion for version SR), and organization of materials. Detailed definitions of these subscales are presented in Table 2. All items were summed and converted to *T*-scores, which provided a gender-and age-normed percentile from a diverse multisite United States sample.^{13,26} A *T*-score of 50 was the mean of the distribution, and any score 65 and higher, 1.5 standard deviations above the mean, was interpreted as elevated and at a greater level of cognitive difficulty.²⁶ Higher scores on the BRIEF indicated more self-reported behavioral disruptions over the past month.

Performance-based executive function measures—Two performance-based executive function measures were administered to assess performance on specific executive domains. The first domain, task-switching was assessed using the Trail Making Test (TMT) A and B.²⁷ TMT-A requires that the participant connect numbered circles in sequential order as quickly as possible (TMT-A). TMT-B requires that the participant connect numbered and letter circles in sequential order in a “number-letter-number” pattern (e.g., 1, A, 2, B, 3, C). Time to complete each task was assessed, and a final TMT score was obtained by subtracting TMT-A from TMT-B to subtract out motor-control effects.^{28,29} In general, TMT has shown consistent adequate reliability coefficients in the .80s across different populations.²⁹

The second performance-based measure administered was Backwards Digit Span (BDS)³⁰ to assess working memory. The measure involved verbal recall of numbers in backwards sequential order than the order verbally presented immediately before. Participants were required to remember the numbers while manipulating the order for correct recall. A raw score was obtained by adding the amount of correctly recalled numbers across BDS trials. In regards to reliability, previous literature has shown BDS to have adequate test-retest reliability and Cronbach's alpha.³¹

A composite executive function (EF) score was computed. Given the relation between TMT and BDS ($r = -.34$, $p = .020$), computing a composite score led to a more parsimonious model thereby allowing testing between the performance-based EF, self-reported BRIEF subscales, and the problematic driving outcomes. The standardized (EF) composite score was calculated for each individual by adding the *z*-score of TMT and BDS scores together. This EF composite score was used in all analyses.

Driving behavior outcomes—Three items assessing self-reported problematic driving outcomes were drawn from a larger, more comprehensive lab developed driving questionnaire focusing on driving perceptions, behaviors while driving, and mobility.⁽³²⁾ The first, *MVCs*, was assessed by the number of MVCs the participant had been involved in over the last five years, the second, *pulled over*, was how many times they were pulled over by the police over the last three years regardless of receiving a ticket, and the third, *tickets*, assessed

by how many times they were issued a ticket after being pulled over. These three driving outcomes were used in lieu of the entire questionnaire, as these were the only questions pertaining to problematic driving outcomes. A trained assistant administered this questionnaire over the telephone during pre-baseline screening. Self-report measures were used in lieu of state crash reports due to evidence that self-report measures of MVC injuries in young adults are valid representations of state reported crash records, sometimes encompassing crashes that are not reported such as single-car crashes or driving while under the influence.³³ Minimal research has been conducted regarding the validity of self-reported tickets and objective measures of tickets from state motor vehicle records. Mixed findings show that self-reported speeding tickets have convergent validity with simulated speeding violations and overall faster simulation driving times³⁴, but low test-retest reliability.³⁵

Data Analysis Plan

Means and standard deviations were calculated for all participant and driving characteristics. Correlations assessed interrelatedness among statistical predictors and outcome variables. Driving characteristics were coded as binary responses (0 = No, 1 = Yes) and were expressed as percentages, total amount of yes responses out of the total amount of responses, due to the rare occurrence of MVCs and traffic incidents. Standardized EF composite scores and BRIEF *T*-scores adjusted for age and gender differences were used in all analyses. Due to the age range of our sample and the use of two BRIEF versions, only BRIEF subscales that were present on both version A and SR were analyzed.

A point-biserial correlation matrix was calculated for each problematic-driving index and a series of binomial logistic regression models were performed to calculate odds ratios and 95% confidence intervals for all significant statistical predictors. To correct alpha inflation for multiple comparisons, the Holm-Bonferroni³⁶ method was used. The Holm-Bonferroni method was chosen over Bonferroni because of its ability to maximize power while still protecting the type I error rate from family-wise alpha inflation.^{37,38}

All resulting significant *p* values for each individual outcome from logistic regression models were sequentially run through the Holm-Bonferroni correction until a non-significant finding was found, stopping further sequential analyses. Each individual binomial logistic regression model contained two predictors: the BRIEF subscale of interest and the EF composite score. All analyses were ran with both the individual TMT and BDS scores along with the BRIEF subscale of interest and compared to the results of analyses with the EF composite score. All analyses were identical in outcome so we preceded with the EF composite score for sample size restrictions (conserving degrees of freedom and reducing the amount of related predictors). The only reported analyses, herein, include the EF composite score. Traditionally, age and gender are also used as covariates in driving research³⁹, but due to power restrictions on predictors in the logistic regression models these two variables were not included. Problematic driving outcomes included the three indices: *MVCs*, *pulled over*, and *tickets*. All increases for odds ratios were interpreted as *T*-score units of change and odds for specific outcome variables at 1.5 standard deviations above the mean (score of 65), the threshold that is interpreted as an elevated level of

cognitive difficulty.^{13,26} All analyses were conducted in SPSS 22.0 for with significance denoted for a p value less than an alpha level of .05.

RESULTS

Preliminary Analyses

Table 1 includes demographic characteristics and problematic driving outcomes. Almost 35% ($n = 16$) of the sample reported one or more MVC over the past five years. Over 50% ($n = 25$) had been pulled over one or more times in the previous three years. Almost 24% ($n = 11$) reported one or more tickets over the previous three years. Average T -scores were computed for BRIEF subscales used in the analysis along with ranges of scores to reflect any individual scores of cognitive difficulties (see Table 3). Average T -scores reflected normal cognitive difficulty in our sample (at or near a score of 50), but as high as 13% of the sample showed elevated cognitive difficulty (a score of 65 or higher) on inhibit, working memory, plan/organize, and organization of material subscales. Also reported in Table 3 is average performance on TMT and BDS along with a range of individual performance.

Correlations addressed the relations between the three outcome variables as all three indices of driving are related to interaction with law enforcement. There was no significant relation between *MVCs* and *pulled over*, ($r = .17$, $p = .259$) or *tickets*, ($r = .16$, $p = .304$). There was a moderately positive significant relationship between *pulled over* and *tickets*, ($r = .45$, $p = .002$), indicating an appropriate level of interrelatedness and not significant multicollinearity.⁴⁰ A Pearson correlation was conducted between all BRIEF subscales and the EF composite score. All BRIEF subscale scores and composite scores were significantly related to one another (see Table 3), while only two were significantly related to the EF composite score (e.g., inhibition and monitor).

Point-biserial Correlation and Regression Analyses

A point-biserial correlation matrix was conducted for each problematic driving outcome variable (see Table 4). The EF composite score was not significantly related to any of the self-reported problematic driving outcomes. Two of the nine BRIEF subscales, working memory ($r_{pb} = .30$, $p = .045$) and planning ($r_{pb} = .41$, $p = .005$) were significantly positively correlated with *MVCs*. Six of the nine subscales (emotional control, inhibit, working memory, plan/organize, task, and organization of materials, $r_{s_{pb}} = .38 - .48$, p 's $< .01$) were positively correlated with *pulled over*. Lastly, three of the nine subscales, inhibit, ($r_{pb} = .48$, $p = .001$), working memory, ($r_{pb} = .31$, $p = .035$), and plan/organize, ($r_{pb} = .32$, $p = .029$) were positively correlated with *tickets*.

Significantly correlated BRIEF subscales were logistically regressed on problematic driving outcome variables (see Table 5). While there were no significant relations between the two performance-based executive function measures or the EF composite score with any of the driving outcomes, the EF composite score was still included as a covariate to account for any variance from performance-based executive measures. Performance-based executive function was not a significant predictor in any regression model. In regards to *MVCs*, plan/organize ($p = .013$), but not working memory ($p = .07$), was significantly associated. This

suggested that for every *T*-score unit increase on the plan/organize subscale, there was a 10% increase in the odds of having a MVC or for every 1.5 standard deviation above the mean, the odds of having a MVC was 3.86 times greater. All six BRIEF subscales (i.e., emotional control, inhibit, working memory, planning, task, and organization of materials) investigated were significantly associated with the increased odds of being *pulled over* (p 's < .05) after alpha inflation correction. With every 1.5 standard deviation above the mean, the odds of being pulled over was 3.03 to 5.96 times greater depending on the subscale. Lastly, the inhibit subscale ($p < .017$), but not the plan/organize ($p > .025$) or working memory subscales ($p > .05$), were associated with *ticket* after alpha inflation correction, suggesting that for every *T*-score unit increase on the inhibit subscale, there was a 14% increase in the odds of receiving a ticket or for every 1.5 standard deviation above the mean, the odds of receiving a ticket was 7.81 times greater.

DISCUSSION

The overall research goal was to fill a gap in the literature concerning higher-order cognitive functioning, and, in particular, the relationship between self-reported executive function and self-reported problematic driving outcomes in a healthy adolescent population. Using the BRIEF, a clinical self-report questionnaire developed to detect executive difficulties through everyday behavior¹², findings indicated that worse self-reported functioning on some executive function subcomponents, but not all, were significantly correlated with higher odds of self-reported problematic driving outcomes. Surprisingly, none of the self-reported problematic driving outcomes were significantly related to our composite score of performance-based executive function. While the lack of association between performance-based executive function measures is contradictory to Mäntylä, Karlsson, Marklund² and Ross, Jongen, Brijs, Ruiter, Brijs, Wets¹¹, it could be the nature of the outcome variable in that both previous studies used simulated driving performance which may pick up more subtle behavioral differences than self-reported problematic driving outcomes as those targeted in the current investigation.

Similar to previous studies using adolescent drivers and performance-based executive function measures^{2,11}, there was a significant relationship between different subcomponents of self-reported executive function and various problematic driving outcomes. Odds ratios revealed that having greater self-reported difficulties with planning and working memory put individuals at greater odds of being pulled over by a police officer, receiving a ticket, or having been involved in a MVC. After correcting for alpha inflation, only increased odds for being pulled over was associated with working memory. In regards to the inhibit subscale, having difficulties with inhibition put an individual at greater odds of being pulled over and receiving a ticket, but not having been in a MVC. Difficulties with task monitoring and organization of materials were associated with greater odds of having been pulled over while there was no association found for emotional control, shifting, or monitoring with any of the problematic driving outcomes.

While our performance-based measures were unrelated to the driving outcomes, the findings with the BRIEF subscales align with previous findings^{2,11} in that working memory and inhibition decrements were associated with negative driving outcomes and not difficulties

with shifting. Our findings add further to the discussion in that more cognitive domains were assessed when compared to previous studies and the usage of self-reported driving outcomes, instead of simulated driving performance. These results allude to the relationship documented between immature executive processes, measured via performance-based measures, in adolescent drivers and their susceptibility to driving errors and increased injury related to risky driving.^{2,3,11} These findings concur with the relationship between self-reported executive difficulties observed via the BRIEF and its relationship with driving deficits in adult clinical populations.^{20,21}

Previous literature with clinical ADHD samples, a developmental disorder with hallmark deficits in inhibition, inattention⁴¹, and working memory⁴², suggests relations between difficulty with inhibition and poor driving performance.^{42,43} This pattern of results is also evident in non-clinical adolescent¹¹ and adult populations.⁴⁴ Difficulties with inhibiting impulsive behaviors could explain the increased odds in having been pulled over and receiving a ticket. Previous work has shown drivers who had previous speeding violations exhibited more impulsive behaviors on performance-based executive function tasks.⁴⁵ Further investigation into the relation between inhibition and MVCs is needed as increased difficulty on the inhibit BRIEF subscale was not associated with the odds of having a MVC in the present study, but has been shown to be associated with problematic driving in other studies.² Previous research has also shown that other executive function domains such as difficulties in planning⁴⁶ and working memory² are also associated with driving performance. However, the mechanisms underlying this association are not yet well understood.

These findings suggest that adolescent drivers may have difficulties with prospective thinking, decision making, and updating information as they gain experience with driving, three processes that have been known to develop beyond adolescence and into adulthood.⁸ There is little research on the relation between task monitoring and organization of materials with problematic driving outcomes. Previous research alludes to the presence of self-monitoring and its moderating effects on driving behavior among older adults, specifically in the context of older adult drivers who moderate their driving behavior based on the belief of their own personal monitoring of ability.⁴⁷ Adolescents, on the other hand, may not self-monitor driving appropriately due to inexperience, propensity to risk-taking, and overconfidence placing them at risk for problematic driving outcomes.⁴⁸ Future research is needed to further elucidate these relations among novice, adolescent drivers as this study did not find a significant association between self-monitoring and any of the problematic driving outcomes, but a significant association between task-monitoring and the instance of being pulled over.

Driving is a complex behavior that relies on multiple areas including experience and cognition. Adolescents are at an increased disadvantage as they have limited experience compounded with underdeveloped executive function abilities.^{2,3,11} Driving begins as a learned behavior that is focused around experience, allowing the behavior to become more automatic over time.⁴⁹ As such, it is likely that young drivers tend to rely on executive functions to aid in developing the proper schemas for novel driving situations. Therefore, deficits in executive functioning would likely result in increases of driving errors, violations,

and problematic driving outcomes related to those processes, especially in a population of inexperienced drivers. Current results support this relation as poorer self-reported executive function, particularly those involved in development of new schema, could manifest as the inability to accurately anticipate future events, not being able to set appropriate goals or carrying them out systematically, inefficiencies in developing appropriate steps in a timely manner ahead of the associated action or event, and inhibiting unwanted behavior.¹⁴

The current study is the first examination of the relationship between the BRIEF and self-reported driving outcomes in a non-clinical sample of adolescents. Rike and colleagues^{20,21} demonstrated that the BRIEF had a direct relationship with self-reported risky behaviors in a sample of clinical adults. The BRIEF contains multiple cognitive subscales of executive functioning, but with the complex definition and division of executive functioning there is overlap and redundancy between the processes as evidenced by the significant inter-correlations found among BRIEF subscales in this study. Because unique contribution of individual cognition domains was the overarching goal of the study individual BRIEF subscales and problematic driving outcomes were investigated and not composite scores. This investigation of individual executive function subscales not only began to explain how executive function interacts with driving in an adolescent population, but also enabled the identification of specific cognitive domains for future research and intervention.

All studies have limitations. Current findings are limited to self-reported driving behaviors, which may be sensitive to bias, and a somewhat limited number of performance-based executive function measures. Observational driving behavior assessed via driving simulators and naturalistic driving are common, objective ways of assessing driving performance, but come with limitations such as costly and time intensive administration and validity issues.⁵⁰ Also because driving outcomes such as MVCs are rare occurrences, self-report is a valid and reliable measure that is used in the driving literature showing to be just as effective, if not better, than state crash reports in the event of collecting data on MVCs.³³ In regards to tickets, the use of driving records would be a stronger, more objective measure of violations as research has shown that test-retest reliability of violations after correcting for mileage is low³⁵, with other studies finding that it has convergent validity with simulator performance.³⁴ Also, only the Trail Making Test (TMT)²⁷ and Backwards Digit Span (BDS)³⁰ were used to assess the performance-based aspect of executive function. Like the BRIEF, it is imperative to assess multiple domains of executive function as not all domains are associated with the behavior of driving.² Future work should explore relationships between multiple domains of performance-based and self-reported cognition with objective and self-reported driving behaviors in adolescents. It is likely that each method is providing different, but important, information about the complex relationship between cognition and driving.

One other limitation is sample size. The current study is of adequate sample size to detect medium to large effects for point-biserial correlations. This is consistent with previous findings assessing the BRIEF's relationship with self-reported driving behaviors.²⁰ Age and gender were not included as separate covariates in our models due to the sample size limitation and for this reason caution is needed when interpreting results. Further investigation of executive difficulty and problematic driving outcomes in a larger sample

while controlling for the effects of gender and age is imperative as both may account for pertinent variation in the context of development and experience. Future studies incorporating larger sample sizes are needed to increase generalizability and finding of small effects. Sample size also was a factor when computing internal consistency. Due to only nine individuals completing the BRIEF-A, Cronbach's alpha was unable to be computed.²⁵ Because the majority of the sample was 18 and younger, all BRIEF-SR scales were considered to have acceptable to good internal consistency.

The generalizability of these findings could be further limited since adolescents that were not the primary drivers of their vehicle were excluded from participating from the larger study. While this may be a limitation, a recent survey from the Insurance Institute for Highway Safety (IIHS) in 2014 found that out of sample of almost 500 families, 71% of parents reported their adolescent to be the primary driver of their vehicle⁵¹, but the lack of sample variability of this study and the IIHS sample may affect interpretability. Over 50% of the sample reported being pulled over at least once by a police officer, and while this number seems high, little research has explored this topic. McCartt, Shabanova, and Leaf⁵² reported that 23% of a sample of 911 high school students reported at least one citation and 28% reported at least one MVC post-licensure. The number of tickets received by participants in the current study is similar to those of McCartt, Shabanova, and Leaf.

In regards to the BRIEF, multiple versions of informant report (i.e., by parents or teachers) are needed to provide a more complete understanding of executive functioning difficulties, as these were not utilized in the current study. While multiple perspectives of self-reported behavior are recommended, especially for populations such as youth with ADHD who may be less aware of their own executive function deficits, the age of this typically developing group of adolescents in this sample was adequate to judge and evaluate their own behavior and perceptions.⁵³ Finally, demographic and health variables such as the presence and interaction of developmental disorders such as IQ performance, ADHD status, drug/alcohol use, and driving experience should be considered in future research to further understand the relation between executive function and problematic driving outcomes. Unfortunately, ADHD symptom severity or status was not assessed in our study sample. Due to previous literature establishing a consistent relation between ADHD and the BRIEF⁵⁴, future studies should explore this covariate in the context of executive difficulties and problematic driving outcomes. ADHD symptoms (i.e., inattention and hyperactivity) are presented along a continuum and have been found to show significant relation to driving errors and violations in a combined sample of non-ADHD and ADHD teens.⁵⁵

Future work should examine the BRIEF compared to a comprehensive executive function battery as a potential screening tool for adolescent drivers in a larger representative sample. Asimakopulos, Boychuck, Sondergaard, Poulin, Ménard, Korner-Bitensky⁷ noted that clinicians are in need for quick, easy, and reliable measures to work in concert to assess overall cognitive functioning and how it relates to driving ability. No single measure of executive function, performance or self-report, adequately predicts all driving deficits or risky behavior to date. The BRIEF in comparison to performance-based tasks would provide an easy to administer assessment of multiple domains of cognition, minimal training, and technology free assessment that can be integrated into a full assessment of fitness to drive. If

used with performance-based tasks, it could offer further insight into behavioral disruptions that are related to certain executive function domains that may overlap with driving abilities and skills.

The relation between the BRIEF and performance-based executive function measures should be investigated, as the reason to the lack of shared variation is empirically unknown, but hypothesized to be partially accounted for by the BRIEF's ecological validity with real-world behavior.^{17,19} The BRIEF is potentially emotionally latent as it relies on self-report, making it a possible example of subjective hot cognition, whereas task switching and working memory performance-based executive function measures are traditional examples of cold cognition.^{56,57} Further investigation and research is needed to determine if this is a viable hypothesis and if it gives more insight into the relation between cognition, emotion, and driving.^{58,59}

Notably, the group means of our adolescent population did not reflect clinical levels of executive function difficulty defined by the BRIEF (i.e., *T*-scores 65 and higher; see ranges in Table 3), but as high as 13% of our sample reflected clinical levels of executive function difficulty for the inhibit, working memory, plan/organize, and organization of material subscales. Further, even with subclinical levels of self-reported executive function difficulty, the BRIEF was significantly associated with problematic driving outcomes. These findings, along with those from clinical patients with TBI and stroke,^{20,21} show the usefulness of the BRIEF in the possible identification of problematic driving areas in different populations of young drivers. While there are mixed results on the efficacy of post-licensure driver training⁶⁰⁻⁶³ evidence has shown that targeting specific driving behaviors and skills during the learning-to-drive phase may be effective in improving the targeted skill and possibly transfer to on-road safety.⁴⁸ This same paradigm could potentially be utilized with the BRIEF to identify specific cognitive processes at the pre-licensure phase for individualized driving training guidelines by incorporating domain specific techniques and strategies into pre-licensure training. For example, if an adolescent pre-driver showed difficulties with planning, possible training efforts could be focused on strategies designed to enhance prospective thinking and decision-making while driving. The BRIEF, while not used directly in training efforts, could be utilized as an empirically based assessment for targeted training in the learning to drive process or a possible tool for clinicians to use to help identify at-risk drivers.

The relationship between the multiple scales of the BRIEF and problematic driving outcomes are key points for driving interventions or pre-driver training regimens. Additional research is needed to address the limitations mentioned above along with needed comparisons between healthy adolescents, adolescents with developmental disabilities, and older counterparts in the realm of executive difficulties and driving to assess how inexperience and driving behavior modifies with exposure.

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Table 1

Adolescent Driver Demographic and Traffic Characteristics

Characteristic	Teen Drivers (<i>n</i> = 46)	
	<i>M</i> (<i>SD</i>)	%
Age (years)	17.41 (1.12)	
Female gender		58.7%
Race		
Caucasian		69.6%
African American		15.2%
Asian		8.7%
Bi-racial		2.2%
Other		4.3%
Years of education	11.02 (1.45)	
Traffic Characteristics ^a		
MVC occurrences (In the last 5 years)		
0		65.2%
1		28.3%
2		6.5%
3+		0%
Pulled over by police (In the last 3 years)		
0		45.7%
1		30.4%
2		13.0%
3+		10.9%
Tickets (In the last 3 years)		
0		76.1%
1		19.6%
2		2.2%
3+		2.2%

Note. MVC = motor vehicle collision.

Self-reported incidents.

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Table 2

Subscales of the BRIEF questionnaire

Subscale	Behavioral Manifestation
Inhibit	The ability to control or inhibit behavior. E.g., “I am impulsive.”
Shift	The ability to transition and switch freely between situations. E.g., “I have trouble changing from one activity or task to another.”
Emotional Control	The ability to appropriately modulate emotional reactions to a situation. E.g., “I have angry outbursts.”
Self-monitor (Monitor, Version-SR)	Awareness of own behavior and its effects on others. E.g., “I don’t know when my actions bother others.”
Initiate (Version-A only)	The ability to start an activity with ease. E.g., “I have problems getting started on my own.”
Working Memory	The ability to hold goal-related information internally for a specific task or reason. E.g., “I forget what I’m doing in the middle of things.”
Plan/Organize	Prospective thinking and anticipation of future events/actions. E.g., “I don’t plan ahead for future activities.”
Task Monitor (Task Completion, Version-SR)	The ability to assess and monitor performance in completing a task. E.g., “I have trouble finishing tasks.”
Organization of materials	The ability to keep environment organized. E.g., “I lose things.”

Table 3
BRIEF T-score and Performance-Based EF Measure Means and Intercorrelations

	<i>M (SD)</i>	Range (Min. – Max)	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Emotion Control	51.76 (11.85)	34 – 82	-												
2. Inhibition	51.89 (10.11)	36 – 74	.45**	-											
3. Shift	51.59 (10.65)	34 – 79	.49**	.60**	-										
4. Monitor	49.98 (9.55)	37 – 66	.47**	.63**	.49**	-									
5. Working Memory	51.46 (9.88)	34 – 72	.47**	.73**	.61**	.56**	-								
6. Plan/Organization	49.93 (10.60)	33 – 73	.58**	.64**	.61**	.50**	.79**	-							
7. Task	50.89 (10.87)	35 – 77	.41**	.51**	.50**	.37**	.69**	.76**	-						
8. Organization of Materials	51.96 (10.23)	36 – 75	.34*	.57**	.58**	.35**	.70**	.72**	.67**	-					
9. BRI	51.50 (10.29)	33 – 75	.79**	.83**	.81**	.73**	.76**	.77**	.60**	.58**	-				
10. MI	51.11 (10.88)	32 – 76	.51**	.69**	.65**	.51**	.90**	.93**	.86**	.86**	.77**	-			
11. GEC	51.33 (10.75)	32 – 74	.67**	.80**	.77**	.64**	.89**	.91**	.78**	.79**	.92**	.95**	-		
12. TMT	29.50 (11.83)	12.64 – 65.07	.04	.24	.09	.23	.16	.06	.17	.14	.16	.15	.16	-	
13. BDS	6.91 (2.23)	4.00 – 13.00	-.07	.12	-.07	.21	.10	.10	.16	.17	.03	.13	.09	.34*	-

Note. BRI = Behavioral regulation index; MI = Metacognitive index; GEC = Global executive composite; TMT = Trail Making Test; BDS = Backwards Digit Span. Higher scores on the BRIEF are indicative of greater self-reported cognitive difficulties. TMT scores ($n = 46$) were obtained by subtracting Trail Making Test-A from Trail Making Test-B with high scores indicating more difficulty with task switching. Lower BDS scores ($n = 46$) indicated a shorter working memory span, or worse performance.

* $p < .05$.

** $p < .01$.

Table 4

Correlation Matrix for Executive Function and Problematic Driving Outcomes

	1	2	3	4
1. MVCS ^f	-			
2. Pulled Over ^f		-		
3. Tickets ^f			-	
4. EF Composite Score	.14	.07	.10	-
5. Emotion Control	.11	**	.09	-.02
6. Inhibition	.14	**	**	* .32
7. Shift	.06	.23	.13	.02
8. Monitor	.22	.26	.23	** .35
9. Working Memory	.30*	**	.31*	.22
10. Plan/Organization	.41**	**	.32*	.14
11. Task	.02	.39**	.23	.29
12. Organization of Materials	.17	**	.26	.27

Note. $n = 46$. MVCS = motor vehicle collisions. EF composite score is a standardized composite of performance on Trail Making Test and Backwards Digit Span Task.

^fPoint biserial correlations.

* $p < .05$.

** $p < .01$

Table 5

Odds ratios

Predictor(s)	Odds of having a MVC (<i>n</i> = 46)		Odds of being pulled over (<i>n</i> = 46)		Odds of receiving of Ticket (<i>n</i> = 46)	
	<i>OR</i>	95% CI	<i>OR</i>	95% CI	<i>OR</i>	95% CI
BRIEF Subscale						
Emotion Control			1.08	1.01 - 1.14 *		
Inhibit			1.11	1.03 - 1.20 **	1.15	1.04 - 1.26 **
Shift						
Monitor						
Working Memory	1.07	1.00 - 1.14	1.12	1.03 - 1.22 **	1.08	1.00 - 1.16
Plan/Organization	1.10	1.02 - 1.17 **	1.12	1.04 - 1.22 **	1.07	1.00 - 1.15 *
Task Completion/Monitor			1.09	1.02 - 1.17 *		
Organization of Materials			1.13	1.04 - 1.22 **		

Note. *OR* = odds ratio; CI = confidence interval. All increases are in *T*-score units of change. Odds ratios were corrected for alpha inflation and significance by the Holmes-Bonferroni adjustment. Higher scores on the BRIEF were indicative of greater self-reported cognitive difficulties.

* $p < .05$.

** $p < .01$.