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Executive function and dangerous driving behaviors in young drivers

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ABSTRACT

The purpose of the present study was to investigate the behavioral and cognitive processes underlying dangerous driving behaviors. We used a survey to assess levels of executive function in college students. The sample consisted of 59 males and 77 females and their age ranged from 18 to 24. We stratified the students into two groups based on executive function scores and compared the extent to which each group engaged in four dangerous driving behaviors (texting while driving, driving without a seat belt, driving while intoxicated, and speeding) as well as how often they experienced three negative driving outcomes (crashes, pulled over, and ticketed). We also investigated how these driving behaviors and outcomes are correlated with subcategories of executive function. The results show that students with a low level of executive function were more likely to engage in dangerous driving behaviors and more likely to experience negative driving outcomes. The results also show that texting while driving, driving while intoxicated, and speeding were most strongly correlated with the executive function subcategory of Impulse Control, whereas driving without a seat belt was most strongly correlated with the executive function subcategory of Strategic Planning. These results suggest that different behavioral or cognitive processes are involved in different dangerous driving behaviors and different interventions may be needed to target each underlying process.

1. Introduction

Although most traffic crashes are predictable and preventable, more than 1.2 million people die each year globally due to traffic crashes with millions more suffering from serious injuries and living with long-term adverse health consequences (World Health Organization [WHO], 2015). Road traffic injuries are the leading cause of death among people aged 15–29 worldwide (WHO, 2015) and among those aged 16–24 in the United States (National Highway Traffic Safety Administration [NHTSA], 2016a). Young drivers have a disproportionately high crash rate. According to NHTSA (2016b), 19.5% of all drivers involved in fatal crashes in 2014 were 15- to 24-years old, despite comprising only 12.2% of all licensed drivers in the United States.

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It is well established that approximately 95% of motor vehicle crashes are attributable to human factors (NHTSA, 2015). In the United States in 2015, for example, 9.9%, 28.1%, 29.3%, and 27.2% of all of the fatalities were due to distraction, unrestrained passenger (i.e., no seat belt use), alcohol impairment, and speeding, respectively (NHTSA, 2016c). Young drivers especially are at higher risk for fatal crashes due to these dangerous driving behaviors. In 2015, 4.9% of young drivers (age 16–24) were observed manipulating electric devices while driving (a major cause of distracted driving), whereas 2.1% of older drivers (age 25–69) were observed doing so (NHTSA, 2016d). Also in 2015, young drivers (age 16–24) had the lowest percentage (86.3%) of seat beat use (NHTSA, 2016e). In fatal crashes in 2015, drivers between 21 and 24 years old had the highest percentage (28%) of drivers with blood alcohol concentrations of 0.08 g/dL or higher at the time of the crash (NHTSA, 2016f). Finally, in fatal crashes in 2014, the percentage of drivers who were speeding at the time of the crash was the highest among drivers aged between 15 and 20 years old (male: 36% and female 20%), which was followed by drivers between 21 and 24 (male: 34% and female: 18%) (NHTSA, 2016g).

The role of human factors in automobile crashes has led to great interest in identifying the behavioral and cognitive variables associated with dangerous driving behaviors and negative driving outcomes (e.g., motor vehicle crashes, speeding tickets). Previous studies have identified several variables, which include but are not limited to (a) demographics, such as gender and age (e.g., Ferguson, Teoh, & McCartt, 2007); (b) personality traits, such as risk-taking propensities (e.g., Clarke, Ward, & Truman, 2005), aggressiveness (e.g., Lajunen & Parker, 2001), sensation seeking (e.g., Schwebel, Severson, Ball, & Rizzo, 2006), and impulsivity (e.g., Pearson, Murphy, & Doane, 2013); and (c) social-cognitive variables, such as attitudes toward traffic safety (e.g., Ulleberg & Rundmo, 2003) and risk perception (e.g., Rhodes & Pivik, 2011).

Given that previous studies have made progress in identifying various predictors for dangerous driving behaviors and negative driving outcomes due to such behaviors, the next important step is to better understand the underlying behavioral and cognitive mechanisms of such behaviors. One area of great interest is *executive function*, which is defined as "cognitive abilities for adaptive functioning, allowing for behavior that is more goal-oriented, flexible, and autonomous" (Spinella, 2005, p. 650). Driving is a complex and goal-directed behavior that relies on various higher-order cognitive processes and therefore is encompassed by executive functions (Mäntylä, Karlsson, & Marklund, 2009). Although researchers have yet to identify a definitive list of components of executive function (Schmeichel & Tang, 2015), major features of executive functions include the following three skills: (a) *inhibitory control*, which refers to deliberately suppressing attention and subsequent responding; (b) *cognitive flexibility*, which refers to thinking about things in multiple ways; and (c) *working memory*, which refers to keeping information mentally and manipulating it in some way (Zelazo, Blair, & Willoughby, 2016). Although these skills are regarded as *neurocognitive* in that they depend on neural circuits involving regions in the prefrontal cortex and other related areas of the brain (Chung, Weyandt, & Swentosky, 2014), executive function is typically assessed behaviorally as three skills (Miyake et al., 2000). For example, the skill of working memory can be assessed behaviorally with the Backwards Digit Span task in which the participant must verbally recall numbers in backward sequential order from the order verbally presented immediately before (Wechsler, 1999).

Previous research has established that levels of executive function are associated with dangerous driving behaviors and negative driving outcomes in older adults (e.g., Daigneault, Joly, & Frigon, 2002) and clinical populations (e.g., Barkley, Murphy, Dupaul, & Bush, 2002; Rike, Ulleberg, Schultheis, Lundqvist, & Schanke, 2014). In Daigneault et al. (2002), for example, cognitive measurements of executive function (response inhibition and cognitive flexibility) were compared between a group of elderly male drivers (65-years old or greater) with a history of motor vehicle crashes and a control group with no history of crashes. The researchers found that the drivers with a history of crashes had poorer performance on all of the executive function tasks, suggesting that executive function is an important factor for dangerous driving behaviors and resultant negative driving outcomes.

Given that the prefrontal cortical system associated with executive function skills continues to develop past adolescence and there are large individual differences in development (Gogtay et al., 2004; Huizinga, Dolan, & van der Molen, 2006), it is reasonable to assume that individual differences in executive function are related to driving performances in young drivers (Guinosso, Johnson, Schultheis, Graefe, & Bishai, 2016). Relative to older adults and clinical populations, less empirical attention has been paid to the relation between executive function and dangerous driving behaviors and negative driving outcomes in young adults. Most studies with young adults employed performance-based assessment of executive function, in which individuals compete a task that is specific to a particular component of executive function such as inhibitory control, cognitive flexibility, and working memory (cf. Toplak, West, & Stanovich, 2013).

Results of previous studies with young adults that employed performance-based measures of executive function provide mixed results, although lower levels of executive function are often associated with poorer simulated driving performance and higher frequencies of dangerous driving behaviors and negative outcomes. Several studies have shown that lower inhibitory control is associated with poorer performance in a simulated driving task (Guinosso et al., 2016; Jongen, Brijs, Komlos, Brijs, & Wets, 2011; Ross et al., 2015; but see Mäntylä et al., 2009) and a higher self-reported frequency of dangerous driving behaviors and negative driving outcomes (Brown et al., 2016; O'Brien & Gormley, 2013; Tabibi, Borzabadi, Stavrinos, & Mashhadi, 2015; but see Starkey & Isler, 2016). Similarly, lower cognitive flexibility is associated with a higher self-reported frequency of negative driving outcomes (Starkey & Isler, 2016), although cognitive flexibility is not associated with performance in a simulated driving task (Guinosso et al., 2016; Mäntylä et al., 2009) and negative driving outcomes (Pope, Ross, & Stavrinos, 2016).

Previous studies that employed working memory tasks have shown mixed results. Poorer *verbal* working memory is associated with poorer performance in a simulated driving task (Mäntylä et al., 2009; Ross et al., 2015) and a higher self-reported frequency of distracted driving (Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). However, verbal working memory is not associated with a self-reported frequency of dangerous driving behaviors (Tabibi et al., 2015) and negative driving outcomes (Pope et al., 2016). Interestingly, better verbal working memory is associated with a *higher* self-reported frequency of dangerous driving behaviors in adolescents (Starkey & Isler, 2016). This counter-intuitive finding is consistent with the finding that better *visuospatial* working memory is associated with a higher rate of dangerous driving behavior in a driving simulated task (Ross et al., 2015). Starkey and Isler reasoned that better working memory may increase drivers' risk taking because such drivers feel confident about dealing with unplanned consequences (Patrick, Blair, & Maggs, 2008).

Recently, self-reported measures of executive function, such as the Behavior Rating Inventory of Executive Function (BRIEF-A; Roth & Gioia, 2005) and the Executive Function Index (EFI; Spinella, 2005), have been employed to examine its relation to dangerous driving behaviors and negative driving outcomes. These studies have shown that lower overall scores of executive function are associated with a higher self-reported frequency of negative driving outcomes (Pope et al., 2016) and distracted driving (Hayashi, Rivera, Modico, Foreman, & Wirth, 2017; Pope, Bell, & Stavrinos, 2017). With respect to components of executive function, these studies are consistent with those with performance-based measures: Lower scores on the subscales most closely related to inhibitory control, cognitive flexibility, and working memory are significantly associated with a higher frequency of texting while driving (Hayashi et al., 2017) and negative driving outcomes (Pope et al., 2016).

Taken together, studies of both older/clinical populations and young drivers generally suggest that executive function is an important factor in understanding the behavioral and cognitive mechanisms that underlie dangerous driving behaviors and related driving outcomes, although there are some inconsistencies. Nevertheless, given young drivers' vulnerability to dangerous driving behaviors and their disproportionately high crash rate, further investigation is warranted to better understand behavioral/cognitive mechanisms underlying dangerous driving behaviors. This is particularly important because a clear understanding of the explanatory pathways to dangerous driving behaviors is required to design targeted and effective interventions for the problem (Brown et al., 2016).

The first purpose of the present study was to investigate whether groups of young drivers with different levels of executive function differ on the frequency of (a) dangerous driving behaviors, such as texting while driving, driving without a seat belt, driving while intoxicated, and driving over the posted speed limit, and (b) other negative driving outcomes, such as the number of crashes, the number of times being pulled over, and the number of times being ticketed. Note that the present study is cross-sectional in nature: We are interested in investigating whether populations of drivers with different levels of executive function differ on measures of dangerous driving behaviors because such information may be useful for effective screening of a target population for interventions. Levels of executive function were assessed with the EFI (Spinella, 2005), a self-reported measure of executive function. The present study also tested the external validity of previous studies (Hayashi et al., 2017; Pope et al., 2016, 2017) by further investigating the feasibility of self-reported measures as a tool to study relations between executive function and dangerous driving behaviors and negative driving outcomes. It was hypothesized that a group of young drivers with a lower level of executive function would report higher frequencies of dangerous driving behaviors and negative driving outcomes.

To develop effective and efficient intervention strategies, one promising approach would be to investigate whether different types of dangerous driving behaviors are inter-related by common processes—namely components of executive function. A common process involved across different types of dangerous driving behaviors suggests the sufficiency of a single type of intervention that targets multiple dangerous driving behaviors. For example, inhibitory control may be a common process through which multiple dangerous driving behaviors can be suppressed. If different processes are involved, however, this suggests that different dangerous driving behaviors need to be treated separately by individualized interventions. For example, strategic planning as a goal-directed behavior that relies on cognitive flexibility (Zelazo et al., 2016) may be an important process for one driving behavior (e.g., driving without a seat belt) but not for others (e.g., texting while driving).

Despite the importance of investigating inter-relations of various dangerous driving behaviors through common cognitive processes, most previous studies (e.g., Tabibi et al., 2015) averaged data from several dangerous driving behaviors and employed a general index of dangerous driving behaviors as a dependent variable. Certainly, various dangerous driving behaviors may co-occur (e.g., Olsen, Shults, & Eaton, 2013). Nevertheless, motivation to engage in different dangerous driving behaviors may differ considerably (Fernandes, Hatfield, & Soames Job, 2010). For example, a decision to reply to a text message while driving may be affected by a different factor than one that affects a decision to drive without wearing a seat belt.

The second purpose of this study was to investigate relations among dangerous driving behaviors and negative driving outcomes, particularly in relation to subcategories of executive function. We analyzed what subcategory of executive function, if any, was associated with each dangerous driving behavior and negative driving outcome, and determined whether or not the same subcategory of executive function was associated with multiple dangerous driving behaviors or negative driving outcomes. To our knowledge, no previous study has investigated the associations among subcategories of self-reported measures of executive function and multiple dangerous driving behaviors in college students (but see Pope et al., 2016, for an investigation of negative driving outcomes in adolescents). We also analyzed inter-correlations among dangerous driving behaviors and negative driving outcomes. Based on previous studies (e.g., Olsen et al., 2013), it was hypothesized that frequencies of dangerous driving behaviors would be inter-correlated. The investigation in relation to the subcategories, however, was exploratory, and thus we had no *a priori* hypothesis.

2. Material and methods

2.1. Participants

One hundred and seventy undergraduate students enrolled in an introductory psychology course at Pennsylvania State University, Hazleton participated. They were offered course credit for participation. Students with no history of driving ($n = 29$) were excluded (i.e., their data were not analyzed). Students older than 25 years old ($n = 5$) were also excluded because the target population of this study was young drivers, which is often defined as drivers younger than 25 years old (e.g., NHTSA, 2016a). The remaining sample consisted of 59 males and 77 females. Mean age, years of higher education, and years driving were 18.8 (*SD* = 1.0; ranging from 18 to 24), 1.4 (*SD* = 0.8; from 0.5 to 5), and 2.4 (*SD* = 1.2; from 0.5 to 7), respectively. In the United States, state governments typically allow licensure of drivers at 16 years old and potential drivers are eligible for provisional learner's permits at 15 years old, though there are state-by-state differences. The Institutional Review Board at the Pennsylvania State University approved the study protocol, and all participants provided written informed consent.

2.2. Procedure

Sessions were conducted in a large classroom. Participants completed a demographic questionnaire, a questionnaire on dangerous driving behaviors and negative driving outcomes, and a questionnaire on executive functioning. Other personality-related and behavioral measures were also obtained, but they are not relevant to the present analyses.

2.2.1. Demographic and driving-related questionnaires

In addition to basic demographic information such as age, gender, years of higher education, and years driving, the participants completed a questionnaire that included questions on the frequency of reading, initiating, and replying to a text message while driving ("How often do (did) you read (initiate or reply to) a text while driving?"), wearing a seat belt ("How often do (did) you wear a seat belt while driving?"), driving while intoxicated ("How often do (did) you drive when you had been drinking alcohol?"), and driving over the posted speed limit ("How often do (did) you drive over the posted speed limit?"). These questions employed a 7-point Likert scale ranging from 1 (*never*) to 7 (*always*). The score for wearing a seat belt was reversed such that a higher score indicates a more frequent occurrence of the dangerous driving behavior. The participants also answered questions on their driving record on traffic accidents[1] ("How many accidents have you had since you got your driver's license?"; hereafter *Accident*), being pulled over ("How many times have you been pulled over for a moving violation?"; hereafter *Pulled Over*), and being ticketed ("How many times have you ticketed for a moving violation?"; hereafter *Ticketed*). These questions were adopted from Schlehofer et al. (2010). Consistent with previous studies (e.g., Pope et al., 2016), the answer on these questions was dichotomized as "0" for no record and "1" for at least one record because of the extreme skewness of the data (78%, 76%, and 80% of the participants reported no record for Accident, Pulled Over, and Ticketed, respectively).

2.2.2. Executive function index

The EFI (Spinella, 2005) is a self-reported measure of executive function. The EFI was chosen because, unlike other self-reported measures of executive function developed for clinical purposes, the EFI was developed with a non-clinical healthy adult population. The EFI consists of 27 questions that are categorized into five subscales (*Motivational Drive*, *Organization*, *Strategic Planning*, *Impulse Control*, and *Empathy*). The subcategories that are most closely related to working memory, cognitive flexibility, and inhibitory control are Organization, Strategic Planning, and Impulse Control, respectively (Spinella, 2005). Each question consists of a 5-point Likert scale ranging from 1 (*not at all*) to 5 (*very much*). The scores from negatively worded items are inverted. The EFI Total scores ranged from 27 to 135 and higher scores on the subscales and the total score represent higher levels of executive functioning. The EFI demonstrates good internal consistency (Cronbach's alpha = .79), and the items associated with prefrontal system dysfunction demonstrate good content validity in clinical and neuroimaging studies (Spinella, 2005).

2.3. Group assignment and data analysis

Consistent with our aim that is cross-sectional in nature, we formed and compared two groups of participants that differed in levels of the EFI: Those who ranked in the top third on the EFI Total score were assigned to the High EFI group, and those ranked in the bottom third were assigned to the Low EFI group. When more than one participant had the same EFI Total score, the score on the Impulse Control subscale was used for the group assignment. For example, three participants had the score of 100 for the EFI Total and only one of them needed to be assigned to the High EFI group to equate the number

[1] We are aware that the terms *crash* and *accident* have different meanings in the traffic injury literature (e.g., Stewart & Lord, 2002). We believe, however, that the term *accident* is still used more commonly in daily conversations and thus it was used in the questionnaires.

of participants between the two groups. The participant whose score on the Impulse Control subscale was the highest among the three was assigned to the High EFI group.

The demographic and the EFI measures were analyzed with an independent sample *t*-test and a chi-square test. The data for texting while driving were calculated by averaging across three types of behaviors (reading, initiating, and replying to a text message). The Mann-Whitney U test was used to compare the frequency of the four dangerous driving behaviors between the High and Low EFI groups because the dependent variables are ordinal. Odds of a negative driving outcome were calculated by dividing the number of participants who experienced each negative driving outcome at least once by the number of participants who had not experienced the outcome. Binary logistic regression was used to estimate odds ratios and corresponding 95% confidence intervals and to test the significance of the difference between the two groups (p values are calculated according to Sheskin, 2003). Partial correlational analyses between the EFI scores and frequencies of dangerous driving behaviors and negative driving outcomes were performed by calculating Spearman correlation coefficients while controlling for all four demographic variables (age, gender, years of higher education, and years driving). Partial correlational analyses were conducted because bivariate correlational analyses revealed that some demographic variables were significantly correlated with some dangerous driving behaviors and negative driving outcomes. The partial correlations were used to reduce the effects of the covariation of the demographic variables and the dangerous driving behaviors on the correlations of interest. Finally, correlational analyses among the dangerous driving behaviors and the negative driving outcomes were performed by calculating Spearman correlation coefficients. All statistical analyses were performed with SPSS Version 24. The statistical significance level for all tests was set at 0.05.

3. Results

Table 1 shows the demographic characteristics and the EFI Total score. No significant differences among groups were found for gender, $\chi^2(1) = 3.67$, $p = 0.056$; age, $t(88) = -1.15$, $p = 0.252$; years of higher education, $t(88) = -0.67$, $p = 0.505$; or years driving, $t(88) = 0.50$, $p = 0.620$.

Fig. 1 shows box plots of the self-reported frequencies of each of the four dangerous driving behaviors for both groups. For all four dangerous driving behaviors, the Low EFI group reported higher frequencies. The Mann-Whitney U tests revealed that there was a statistically significant difference with texting while driving, $U = 597.00$, $p = 0.001$, $r = 0.35$; driving without a seat belt, $U = 778.50$, $p = 0.026$, $r = 0.24$; driving while intoxicated, $U = 719.50$, $p = 0.001$, $r = 0.34$; and speeding, $U = 567.50$, $p < 0.001$, $r = 0.39$.

Table 2 shows odds of the negative driving outcomes and odds ratios for both groups. The odds of all negative driving outcomes among the Low EFI group are approximately 3 times higher than those among the High EFI group, indicating the Low EFI group is approximately three times more likely to experience the negative driving outcomes. All odds ratios are statistically significant ($ps < 0.05$).

Table 3 shows partial correlation coefficients (Spearman's rho) among the EFI, dangerous driving behaviors, and negative driving outcomes while controlling for all four demographic variables (age, gender, years of higher education, and years driving). Consistent with the data in Fig. 1, EFT Total was significantly negatively correlated with texting while driving, $\rho(130) = -0.22$, $p = 0.012$; driving without a seat belt, $\rho(130) = -0.20$, $p = 0.019$; driving while intoxicated, $\rho(130) = -0.26$, $p = 0.003$; and speeding, $\rho(130) = -0.24$, $p = 0.006$. There was no significant relation between EFI Total and any of the negative driving outcomes. However, the EFI subscale of Impulse Control was significantly negatively correlated with all three: Accident, $\rho(130) = -0.19$, $p = 0.027$; Pulled Over, $\rho\ (130) = -0.18$, $\rho = 0.036$; and Ticketed, $\rho(130) = -0.20$, $p = 0.021$.

The comparisons among the four dangerous driving behaviors revealed one noticeable pattern: Driving without a seat belt was somewhat different from other three driving behaviors. First, with respect to the relations to subcategories of the EFI (Table 3), Impulse Control was most strongly correlated with texting while driving, $\rho(134) = -0.37$, $p < 0.001$; driving while intoxicated, $p(134) = -0.31$, $p < 0.001$; and speeding, $\rho(134) = -0.39$, $p < 0.001$, whereas Strategic Planning was most strongly correlated with driving without a seat belt, $\rho(134) = -0.26$, $p = 0.004$. Second, correlational analyses among the four driving behaviors (Table 4) revealed there were significant positive correlations between texting while driving and driving

Table 1
Demographic characteristics and EFI total score for both groups.

Characteristics	Low EFI	High EFI
Gender		
Male	24	15
Female	21	30
Age in years	18.6 (0.9)	18.9 (1.3)
Years of higher education	1.3 (0.8)	1.5 (1.1)
Years driving	2.4 (1.1)	2.3 (1.5)
EFI total[a]	82.0 (7.3)	107.9 (6.5)

Note. Values are means (and standard deviations) except for Gender
[a] Mean difference depicts the results of the stratification.

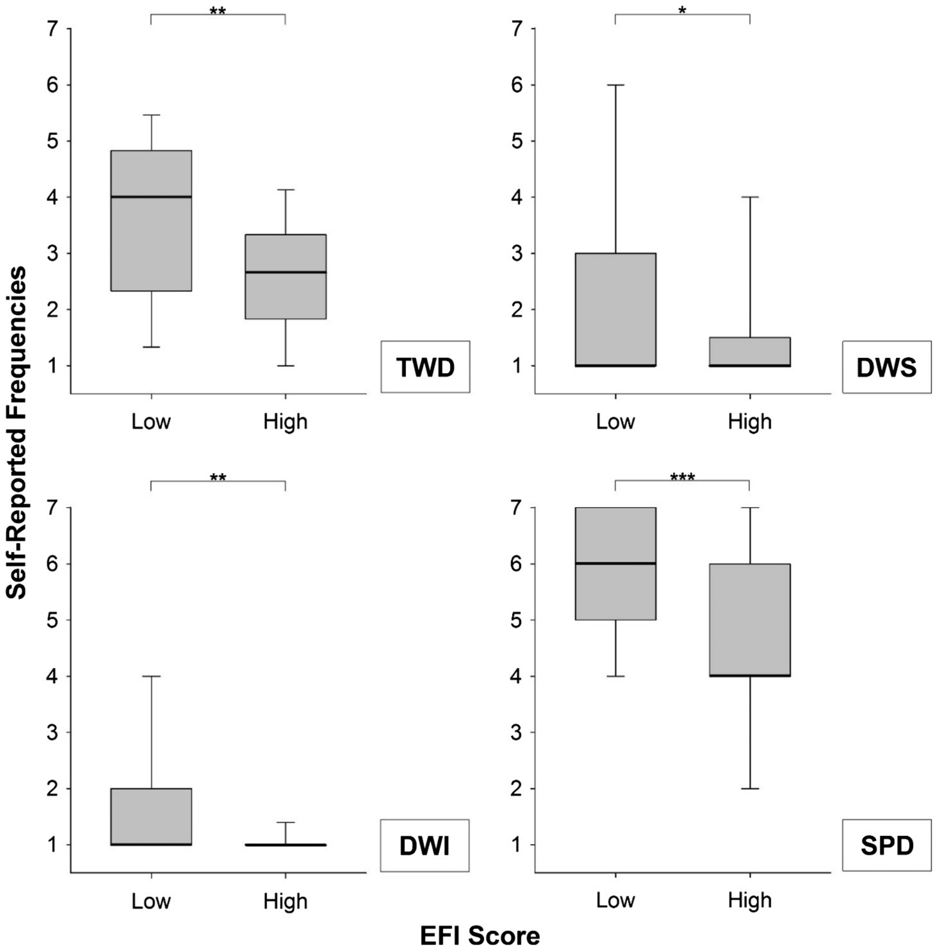

Fig. 1. Box plots of self-reported frequencies of texting while driving (TWD), driving without a seat belt (DWS), driving while intoxicated (DWI), and speeding (SPD) for the Low and High EFI groups. The box for each group represents the interquartile range (25th and 75th percentile) and the thick vertical line within the box indicates the median value. Bottom and top bars of the whisker indicate the 10th and 90th percentiles, respectively. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

Table 2
Odds of negative driving outcomes, odds ratios, and confidence intervals for both groups.

	Odds		OR	95% CI	*p*
	Low EFI	High EFI			
Accident	0.406 (13/32)	0.125 (5/40)	3.25	[1.05, 10.07]	0.041
Pulled over	0.607 (17/28)	0.216 (8/37)	2.81	[1.06, 7.43]	0.038
Ticketed	0.452 (14/31)	0.154 (6/39)	2.94	[1.01, 8.53]	0.048

Note. EFI = Executive Function Index. OR = odds ratio. CI = confidence interval. The numbers in parentheses indicate the number of participants who reported at least one instance of each negative driving outcome/the number of participants who reported no instance.

while intoxicated, $\rho(134) = 0.32$, $p < 0.001$; between texting while driving and speeding, $p(134) = 0.54$, $p < 0.001$; and between driving while intoxicated and speeding, $\rho(134) = 0.32$, $p < 0.001$, whereas driving without a seat belt was not significantly correlated with any of the other three driving behaviors.

Analyses on the relations between dangerous driving behaviors and negative driving outcomes (Table 4) revealed that texting while driving was significantly positively correlated with Accident, $\rho(134) = 0.18$, $p = 0.035$; Pulled Over, $\rho(134) = 0.30$, $p < 0.001$; and Ticketed, $\rho(134) = 0.28$, $p = 0.001$. Driving while intoxicated was significantly positively correlated with Pulled Over, $\rho(134) = 0.17$, $p = 0.049$; and Ticketed, $\rho(134) = 0.19$, $p = 0.029$. Finally, among driving records, Accident was significantly positively correlated with Pulled Over, $\rho(134) = 0.24$, $p = 0.006$, and Pulled Over was significantly positively correlated with Ticketed, $\rho(134) = 0.84$, $p < 0.001$.

Table 3
Partial spearman correlational coefficients among EFI subscales, Dangerous driving behaviors, and driving records.

	MD	ORG	SP	IC	EM	Total
Texting while driving	0.04	−0.14	−0.11	−0.37***	−0.15	−0.22*
Driving without a seat belt	−0.11	−0.04	−0.26**	−0.05	−0.16	−0.20*
Driving while intoxicated	0.04	−0.05	−0.23*	−0.31***	−0.12	−0.26**
Speeding	0.01	−0.07	−0.15	−0.39***	−0.03	−0.24**
Accident	0.00	−0.08	−0.16	−0.19*	−0.04	−0.16
Pulled over	0.00	−0.03	−0.10	−0.18*	−0.11	−0.13
Ticketed	0.01	−0.05	−0.10	−0.20*	−0.05	−0.12

Note. All demographic variables (age, gender, years of education, and years driving) are controlled for. MD = Motivational Drive. ORG = Organization. SP = Strategic Planning. IC = Impulse Control. EM = Empathy.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 4
Spearman correlation coefficients of dangerous driving behaviors and driving records.

	1	2	3	4	5	6	7
1. Texting while driving	–						
2. Driving without a seat belt	0.02	–					
3. Driving while intoxicated	0.32***	0.14	–				
4. Speeding	0.54***	0.07	0.32***	–			
5. Accident	0.18*	0.03	0.15	0.07	–		
6. Pulled over	0.30*	0.04	0.17*	0.12	0.24**	–	
7. Ticketed	0.28*	0.03	0.19*	0.16	0.14	0.84**	–

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

4. Discussion

The first purpose of the present study was to investigate whether groups of young drivers stratified by levels of executive function differed in how frequently they engaged in dangerous driving behaviors and experienced negative driving outcomes. The results show that students with a lower overall score of executive function, as measured by the EFI, were more likely to engage in texting while driving, driving without a seat belt, driving while intoxicated, and speeding. The results also show that students with a lower overall executive function score were more likely to experience all three negative driving outcomes: Accident, Pulled Over, and Ticketed.

The present study increases the external validity of the previous studies that showed an inverse relation between self-reported measures of executive function and frequencies of distracted driving (Hayashi et al., 2017; Pope et al., 2017) and negative driving outcomes (Pope et al., 2016) in two important ways. First, the present study extended the measurement to various dangerous driving behaviors other than distracted driving and showed that other behaviors are similarly affected by executive function. Second, unlike Pope et al. (2016, 2017) that employed the BRIEF, the present study and Hayashi et al. (2017) employed the EFI, which was developed with a non-clinical healthy adult population (Spinella, 2005). Taken together with the previous studies, the present study demonstrated the feasibility of self-reported measures as a tool to examine relations between levels of executive function and dangerous driving behaviors and negative driving outcomes in young drivers.

The second purpose of this present study was to investigate relations among dangerous driving behaviors, particularly in relation to subcategories of executive function. The results show that texting while driving, driving while intoxicated, speeding, and all three negative driving outcomes were most strongly correlated with the subcategory of Impulse Control, whereas driving without a seat belt was most strongly correlated with the subcategory of Strategic Planning. The results also show that texting while driving, driving while intoxicated, and speeding were inter-correlated, whereas driving without a seat belt was correlated with none of other dangerous driving behaviors.

These findings may indicate that texting while driving, driving while intoxicated, and speeding share a common behavioral/cognitive process—namely Impulse Control, which addresses self-inhibition, risk taking, and social (mis)conduct (Spinella, 2005). Driving without a seat belt is somewhat distinct from the other three dangerous driving behaviors, and Strategic Planning, which addresses tendencies to think ahead, plan, and use strategies (Spinella, 2005), is an important behavioral/cognitive process. Although no clear line can be drawn, texting while driving, driving while intoxicated, and speeding may be best conceptualized as forms of impulsive behavior due to lack of inhibitory control or insensitivity to delayed rewards (de Wit, 2009). This is consistent with previous studies demonstrating that various types of impulsivity are associated with these dangerous driving behaviors (e.g., Hayashi, Miller, Foreman, & Wirth, 2016; Hayashi, Russo, & Wirth, 2015; O'Brien & Gormley, 2013; Paaver, Eensoo, Pulver, & Harro, 2006).

On the other hand, driving without a seat belt (and driving while intoxicated to some extent) may be best conceptualized as a form of risk-taking: *purposive* reward-seeking despite potential negative consequences (Ben-Zur & Zeidner, 2009). Individuals do not engage in dangerous behaviors solely due to lack of inhibitory control. Instead, they may be more motivated by the potential for reward of some kind, and less deterred by the potential for punishment (Weafer, Milich, & Fillmore, 2011). Risk-taking defined in this manner is in part due to lack of appropriate planning, for which cognitive flexibility—or thinking about something in multiple ways (Zelazo et al., 2016)—plays an important role. Consistent with this notion, previous research has shown that risk-taking propensities, as measured by the Balloon Analogue Risk Task, are negatively associated with seat best use (Lejuez et al., 2002). In addition, a personality-trait of sensation seeking, which is defined by "the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal, and financial risks for the sake of such experiences" (Zuckerman, 1994, p. 27), is positively associated with driving without a seat belt (e.g., Wilson, 1990).

It is important to note that some behaviors are both impulsive and risky (Cross, Copping, & Campbell, 2011). In this study, driving while intoxicated was significantly negatively correlated with both Impulsive Control and Strategic Planning (although the correlation was stronger with Impulsive Control). Perhaps, driving while intoxicated is a joint function of two components of executive function: inhibitory control and cognitive flexibility (planning). Although the correlations were not significant and thus results should be interpreted with caution, texting while driving and speeding were also negatively associated with Strategic Planning, suggesting the possibility of the similar joint function. Interestingly, there was no significant correlation between driving without a seat belt and Impulse Control, which may suggest that inhibitory control is not an important factor for the dangerous driving behavior.

4.1. Potential intervention strategies

The present study found that three dangerous driving behaviors, texting while driving, driving while intoxicated, and speeding, may share a behavioral/cognitive mechanism (i.e., inhibitory control), and this may suggest that a similar intervention strategy targeted to act on inhibitory control may be useful for reducing these three dangerous driving behaviors. For example, a self-regulation training (Hofmann, Schmeichel, & Baddeley, 2012) that strengthens inhibitory control for alcohol-related cues through repeatedly stopping prepotent responses toward the cues (i.e., go/no go task) decreases actual alcohol intake in college students (Houben, Nederkoorn, Wiers, & Jansen, 2011). This is consistent with a neuroimaging study showing that improvement in inhibitory control resulted in increased activity in areas of the prefrontal cortex associated with inhibitory control (Berkman, Kahn, & Merchant, 2014). Furthermore, the application of transcranial direct current stimulation (tDCS) on the dorsolateral prefrontal cortex, which is hypothesized to strengthen executive control, reduced dangerous driving behavior in a driving simulator task (Beeli, Koeneke, Gasser, & Jancke, 2008). Taken together, although the transfer of the positive effects from self-regulation trainings to actual driving behaviors needs to be tested with caution, it is at least plausible that some forms of self-regulation training to improve inhibitory control could be effective for reducing driving while intoxicated. If this is the case, then the effects of the training may generalize to other dangerous driving behaviors (texting while driving and speeding) that share the same cognitive mechanism. Further research is needed to test this hypothesis.

The present results, however, may indicate that the training to improve inhibitory control is not effective for driving without a seat belt because a different process (cognitive flexibility or planning) is involved. A different strategy, which acts on such a process, is necessary for this dangerous driving behavior. A longitudinal study using the Health Action Process Approach (HAPA) model conducted by Schwarzer et al. (2007) showed that outcome expectancies (i.e., positive outcomes of seat belt use) predict self-reported seat belt use through the mediation of intentions and planning to use a seat belt. This may suggest that some forms of campaigns that focus on the benefits of seat belt use, rather than the negative outcomes of no seat belt use, may be an effective approach (Şimşekoğlu & Lajunen, 2008). On the other hand, similar campaigns are certainly important but may not be very effective for other types of dangerous driving behaviors because, according to the present results, the primary process for these behaviors is lack of inhibitory control. Indeed, with respect to cell phone use while driving, for example, there is no empirical evidence suggesting that educational campaigns have had any effect on the problem (Delgado, Wanner, & McDonald, 2016).

In summary, in developing intervention strategies, it is important to consider the different underlying processes involved in dangerous driving behaviors. Texting while driving, driving while intoxicated, and speeding as forms of impulsive behavior would benefit from strategies that act on the process of inhibitory control, whereas driving without a seat belt as a form of risk taking behavior would benefit from strategies that act on the process of cognitive flexibility or strategic planning.

4.2. Limitations

Four limitations of the present study are noteworthy. First, the dependent measures related to dangerous driving behaviors are self-reported. It has been known that there is a tendency by participants to underreport socially inappropriate behavior (Wentland, 1993). For example, a study on seat belt use found that 75% of drivers self-reported they always used a seat belt, but only 61.5% of them were observed wearing a seat belt (Parada, Cohn, Gonzalez, Byrd, & Cortes, 2001). Naturalistic driving studies, which rely on the recording of direct, observational data (e.g., taken from an on-board camera; Klauer et al., 2014), would be ideal in future research. With respect to the validity of self-reported measures of negative driving outcomes, the empirical evidence is mixed. For example, Roberts, Vingilis, Wilk, and Seeley (2008) found that self-reported measures of injuries due to motor vehicle crashes are valid representations of police-reported crash records, whereas af Wåhlberg and Dorn (2015) found that test-retest reliability of self-reported accidents and traffic violations is low. At any rate, if self-reported data of dangerous driving behaviors and negative driving outcomes are subject to underreporting bias or random error, it would be difficult to reject the null hypothesis that groups with different levels of executive function do not differ in terms of frequencies of dangerous driving behaviors and negative driving outcomes. Therefore, we believe the overall conclusions of the present study are tenable; however, the results of the present study, as with any study employing self-reported data, should be interpreted with caution, and it is important for future research to replicate the findings using objective measures.

Second, the measures of executive function were also self-reported. Self-reported measures are subjective in nature, and their ability to accurately assess individuals' levels of executive function depends entirely on the individuals' self-evaluation of their own behaviors across different settings over long periods of time (Spinella, 2005). Performance-based assessments of executive function are often standardized and more objective because they do not depend on individuals' self-evaluation. It is important to note, however, that performance-based measures are taken in a controlled environment and may not generalize to an individual's everyday situations (Reid, McKittrick, Davtian, & Fong, 2012). Self-reported measures, on the other hand, have high ecological validity by providing information about an individual's levels of executive function that are more typical in everyday situations (Spinella, 2005). In addition, self-reported measures are more cost effective and efficient ways of assessing levels of executive function, and, at a minimum, self-report assessments can serve as a screener to evaluate whether additional testing is needed (Reid et al., 2012). In this sense, both types of measures are mutually supportive and each measure should be utilized considering both advantages and disadvantages.

Third, the sample exclusively consisted of college students aged between 18 and 25 and the sample size was relatively small. They are fairly a homogeneous group, and thus the conclusions of the present study are only applicable to this population. Previous research has shown that levels of executive function are associated with IQ score (Ardila, Pineda, & Rosselli, 2000), age (Huizinga et al., 2006), and years of education (Spinella, 2005). A future study that uses a more diverse and larger sample should test the generalizability of the results of the present study. Nevertheless, it is important to note that young college students are one of the most important target populations who are at high risk of motor vehicle crashes due to, for example, texting while driving (Atchley, Atwood, & Boulton, 2011). In this sense, the use of college students can be considered both a limitation and a strength of the present study (Feldman, Greeson, Renna, & Robbins-Monteith, 2011).

Finally, the negative driving outcomes are analyzed only dichotomously. Some accidents involve fault and others do not. The severity of accidents also differs widely (e.g., the ones with or without injury). We did not collect such information in our questionnaires, but future research should take these factors into consideration and provide more detailed analyses. In addition, although the probability of experiencing negative driving outcomes would be affected by how frequently the participants drive (e.g., only once a month or daily), we did not collect the information and this variable was not controlled for in our analyses. Future research should collect and control for this information.

4.3. Conclusion

The present study investigated behavioral and cognitive processes underlying dangerous driving behaviors with college students. The results show that students with a higher overall score of executive function, as measured by the EFI, were less likely to engage in all four types of dangerous driving behaviors and were less likely to experience negative driving outcomes. In terms of dangerous driving behaviors and their relations to the subcategories of executive function as measured by the EFI, texting while driving, driving while intoxicated, and speeding were most strongly correlated with the subcategory of Impulse Control, whereas driving without a seat belt was most strongly correlated with the subcategory of Strategic Planning. Additional research should incorporate performance-based executive function tests to evaluate convergent validity, extend the analysis to other dangerous driving behaviors (e.g., tailgating, running red lights), and evaluate intervention strategies to reduce dangerous driving behaviors related to impulse control and strategic planning. Understanding how levels of executive function affect safe and unsafe driving behaviors may go a long way in developing effective intervention and prevention strategies to ultimately reduce roadway injuries and fatalities.

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