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Driving After Concussion: Clinical Measures Associated with Post-concussion

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Methodology- Kumiko Hashida, Julianne Schmidt
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Driving After Concussion: Clinical Measures Associated With Postconcussion Driving

Abstract

Context: Post-concussion driving assessment has been limited to driving simulators, which are not clinically feasible. There is a need to equip clinicians with tools that can assist in making recommendations on return to driving.

Objective: To determine the association between clinical measures and driving simulator performance in college students within a week of a concussion.

Design: Cross-sectional.

Setting: Laboratory.

Patients or Other Participants: Forty-three college students with concussion and 46 controls.

Main Outcome Measures: Clinical outcomes include: total symptom score, dual-task tandem gait completion time and dual-task cost (the percentage increase in completion under dual-task and single-task), Complex Figure performance, Useful Field of View performance, and Vestibular Ocular Motor Screening (VOMS) symptom provocation score. Driving simulator outcomes include: the number of collisions, speed exceedances, stop signs missed, centerline crossings, and road edge excursions. Within each of the drive segments, we collected standard deviation of speed (SDS) and lane position (SDLP). Separate models for each clinical assessment and driving outcome with negative binomial and linear regression models were used.

Results: Greater dual-task cost was associated with increased road edge excursions (p=.018) and SDS (p=.009). Higher VOMS symptom provocation was associated with less SDS (all p<.050). A higher Complex Figure copy score was associated with decreased centerline crossings (p=.001), road edge excursions (p<.001), SDS (p<.001), and SDLP (all p<.050). A slower Complex Figure copy completion time was associated with lower SDS (p=.010). A higher

Complex Figure delayed score was associated with fewer road edge excursions and lower SDLP (all p<.050). Longer Complex Figure delayed completion time was associated with greater SDS (p=.03).

Conclusions: Dual-task and Complex Figure might be useful when assessing post-concussion driving ability. Higher VOMS symptom provocation was associated with better driving performance, possibly indicating individuals experiencing vestibular-oculomotor symptoms may adopt more cautious strategies.

294/300 words

Key Words: Concussion, Return to Drive, Concussion Assessment, Driving After Concussion.

Key Points:

- Dual-task tandem gait and Complex Figure might inform simulated driving performance among individuals with concussion.
- VOMS does not directly measures driving ability, but it may offer insight into compensatory behavior.

1. Introduction

Concussions have become a growing area of public concern. The annual incidence of concussions is estimated to be more than 10,000 concussions in collegiate settings in the United States of America.[1] The presentation and duration of concussion signs and symptoms vary in each individual, but individuals with concussion often suffer from cognitive, motor, emotional, and vestibular-ocular dysfunctions that may last days, weeks, or even longer after the injury despite being symptom-free.[2] These post-concussion deficits could have a significant impact on the ability to drive.[3-7] During the acute phase of the injury, individuals with concussion demonstrate poorer driving performance relative to controls.[5,8] Additionally, individuals with a history of concussions have twice as many motor vehicle crashes as those without a previous history of concussions, though underlying factors may contribute to this association.[4] These noted driving impairments following concussion support the need for the development of strategies to promote a safe return to driving after concussion.

Driving, one of the important activities of daily living, enables us to transport and engage in social activities. Reduction and cessation of driving can result in negative consequences such as reduced social involvement, increased isolation, poor mental health, and diminished well-being.[9] Thus, it is important to allow an individual to return to driving as soon as it is safe to do so. Despite the importance of driving, driving assessment expertise and technology are not accessible in most clinical settings managing concussion. Therefore, there is a need to equip clinicians with objective tools that can assist in making clinical recommendations on return to driving.

Our study highlighted that specific symptom clusters and neurocognitive assessments uniquely captured the simulated driving performance during the acute phase of the concussion.[10]

However, symptoms resolve relatively quickly while individuals may still experience residual deficits associated with concussion.[11,12] Additionally, symptom assessments rely on subjective reporting which raises concerns of reliability in understanding recovery of post-concussion driving performance.[13] Thus, we need to identify an effective approach to objectively assess post-concussion driving performance over a longer period.

The current international consensus statement for concussion includes assessments of symptoms, cognitive, postural control, and more recently, vestibular performance.[14] However, these assessments do not include tests of divided attention, visuospatial attention, and visual memory assessments – domains commonly correlated with driving performance. In order to objectively evaluate driving performance, this study included a combination of clinically accessible tests relevant to driving performance. The Useful Field of View test (UFOV),[15] Rey–Osterrieth complex figure test (ROCF),[15] and dual-task (DT) test [16] are commonly implemented to assess driving safety in older adults and after brain injury in clinical settings. Additionally, one preliminary study found that vestibular ocular motor screening (VOMS) outcomes were uniquely associated with simulated driving performance in individuals deprived of sleep.[17] These clinical measures which can be administered within 20 minutes, may offer a more comprehensive understanding of the symptoms impacting driving ability in individuals following concussion. No study has examined whether these clinical measures can capture driving performance following concussion. Therefore, the purpose of the study was to determine the association between clinical measures and post-concussion driving performance in college students within a week of the concussion. It was hypothesized that poorer UFOV, Complex Figure, DT tandem gait, and VOMS outcomes would be associated with poorer simulated driving performance in the concussion group, relative to the controls.

2. Methods

A cross sectional study design was employed for this study. One group consisted of non-concussed controls and the other consisted of individuals within a week of concussion. Individuals with concussion were diagnosed with a concussion in accordance with the fifth Consensus Statement on Concussion in Sport within a week of the injury.[18] The inclusion criteria for all participants were: ages between 18 and 25 years old, possess a valid class C driver's license, and normal or corrected-to-normal vision. Class C driver's license is the most common type of license allowing individuals to drive any self-propelled or towed vehicle used for recreational, camping, or travel purposes as well as for personal or family transportation.[19] The exclusion criteria were: a history of more than 3 previous self-reported concussions, other major neurological disorders/injury, current use of any medications that evoke drowsiness (prescription or over the counter), or heavy use of alcohol (binge drinking 5+ days in the past 30 days), or any illegal drug use.

All participants completed a driving simulator assessment, self-reported symptom checklist of Sport Concussion Assessment Tool – 5th, DT tandem gait, UFOV, Complex Figure, and VOMS during the initial evaluation. Data collection occurred in quiet indoor facilities with minimal distractions at the university laboratory. Participants signed an Institutional Review Board consent form. It took 35-45 minutes to complete all assessments.

2.1.1. Driving simulator

All participants completed a driving simulation task on a simulator with three 23" screens on STISIM drive® software, model 100WS, version 3.15.07 (STI Inc, Hawthorne, CA). A Logitech® G29 steering wheel and pedals were connected to the computer and used to control the driving simulator.[5,7] After a brief explanation of the procedure, participants were asked to perform a 1-minute familiarization drive task. The assessment consisted of a 6-mile route of simulated daily traffic scenarios, including navigation through the following segments: 1) overtaking on a highway, 2) traffic light, 3) highway left curve, 4) highway right curve, 5) child pedestrian crossing, 6) cross walk, 7) residential right curve, 8) residential left curve, 9) incurring vehicle in the lane, 10) vehicle cross: navigating to the left of a car crash in the right lane, and 11) a vehicle following task. Segments were completed once and in the same sequence for all participants, as is common with driving simulation scenarios.[3]

Outcome variables were extracted from the STISIM drive® software data files and processed using MATLAB. The total number of collisions, speed exceedances, stop signs missed, centerline crossings, and road edge excursions were used as full drive outcomes. Within each of the 11 drive segments listed above, standard deviation of speed (SDS) and average standard deviation of lane position (SDLP) were extracted due to their sensitivity to vehicle control and crash risk.[20] Lower SDS and SDLP indicate consistent speed and vehicle position control, considered to be better driving performance.

2.1.2. Symptoms

All participants completed the Sport Concussion Assessment Tool-5th symptom checklist.[21] It consists of 22 items on a scale from 0 (none) to 6 (most severe). The total symptom score was calculated and used as an outcome measure.

2.1.3. Dual Task Tandem Gait Test

During the dual task (DT) tandem gait, the participant performed tandem gait and serial sevens simultaneously. The participant walked with a heel-to-toe alternate gait on a straight 3-meter line of athletic tape. At the end of the line, the participant turned 180 degrees and used the same gait to return to the starting point as quickly as possible. The participant was given a random number at the beginning of the test and was instructed to count backward by sevens throughout the tandem gait. The separation of heel and toe and/or stepping off the tape was considered a failed trial, and participants performed another trial until 2 successful trials were completed. The time (seconds) taken to complete the task was recorded using a stopwatch on a mobile device.[14] We then calculated the average time (seconds) of 2 successful trials. In addition, dual-task cost (DTC) was calculated using the following formula: $\frac{\text{DT} - \text{single task}}{\text{single task}}$ X 100 to show performance change under DT conditions relative to single-task performance. A higher DTC indicates a greater decline in performance by the added cognitive task.

2.1.4. Useful Field of View

UFOV (Visual Resources, Inc., Bowling Green, KY) is a computer-based test to assess visual functions pertinent to driving safety. It consists of three sub-tests: processing speed, divided attention, and selective attention. The processing speed subtest measures the speed at which an individual can process visual information. Participants are shown a visual stimulus (e.g., a car or truck icon) in the center of the screen and must identify it as quickly and accurately as possible. The display duration decreases progressively, challenging the participant's visual processing efficiency. The divided attention subtest evaluates the ability to process visual information simultaneously in central and peripheral vision. Participants are required to identify a central target (as in the first subtest) while also localizing a peripheral target (e.g., a briefly displayed car in one of eight radial positions). The selective attention subtest is similar to the divided attention subtest but adds 47 distractors to increase difficulty. The shortest time (in ms) to complete each subtest with at least 75% accuracy was the outcome measure.

2.1.5. Complex Figure

The Complex Figure is an adapted version of the ROCF, consisting of a copy trial and a delayed recall trial. During the copy trial, the participant was instructed to copy the complex figure onto a blank sheet of paper as accurately as possible. The Complex Figure copy trial assesses the visuospatial ability which can provide an individual's capacity to detect hazards and react to situations appropriately. During the delayed trial, the participant was instructed to recall the figure and reproduce it from memory after 30 minutes of completing the copy trial. The Complex Figure delayed trial assesses delayed memory which can provide information about an individual's ability to remember speed limits and traffic signs while driving. The time (seconds) taken to complete the task and the score of how correctly the units were drawn were used as outcome measures. The Complex Figure is divided into 18 units for both copy and delayed trials. Each unit is scored as follows: 2 points for an accurate figure and correct placement, 1 point for an accurate figure and incorrect placement or an inaccurate figure and correct placement, 0.5 points for an inaccurate figure but recognizable and incorrect location, and 0 points for a missing figure that cannot be recognized. The maximum score was 36.[22] Each trial takes about 5 minutes to complete.

2.1.6. Vestibular-Ocular Motor Screen

VOMS consists of five domains utilizing ocular and vestibular function: 1) smooth pursuit, 2) saccades, 3) near point convergence, 4) VOR, and 5) visual motion sensitivity. Before the VOMS test and after each domain, participants rated their symptoms of headache, dizziness, nausea, and fogginess on a scale from 0 to 10, where 0 indicates no symptoms and 10 indicates severe symptoms. The change score of total symptom scores of headaches, dizziness, nausea, and fogginess from the pre-test symptoms to total symptom scores after each domain was calculated (Post-test symptom - Pre-test Symptom) and used as outcome measures.

2.2. Statistical Analysis

Prior to analysis, all data were loaded and cleaned using Microsoft Excel©. Data were then loaded into Statistical Package for Social Science (SPSS) Version 29 (IBM®, Chicago, IL) with an alpha level of $p < 0.05$ for analysis. Independent samples t-test, Mann–Whitney U-test, or chi-square test were used to compare demographic characteristics and clinical measure outcomes between groups. To address our aim, separate models for each assessment and driving outcome were conducted; negative binomial regression was used for count outcomes, while linear regression models were used for continuous outcomes (sometimes with a natural log transformation). Predictors included the clinical assessment outcome, group, and the interaction between assessment and group. This manuscript focuses on the interaction effect between group and clinical concussion assessment to account for the possibility that some assessments relate to driving in healthy, non-concussed individuals. A significant interaction provides evidence that the relationship between clinical assessment and driving outcome differs between groups and that a correlation is unique to the concussion group. We did not adjust for multiple comparisons in our analysis because our primary focus was on exploring data. This is especially relevant given the small sample size and lack of evidence related to driving after concussion.

3. Results

Forty-three individuals with concussion and 46 non-concussed controls completed driving simulation assessment, symptom checklist, DT tandem gait, UFOV, Complex Figure, and VOMS within a week post-concussion (Table 1). Some clinical measures were included in the protocol, resulting in missing data.

3.1. Symptom

There were no interaction effects between group and total symptom scores for driving simulation outcomes (*p*>0.05, Table 2-4).

3.2. Dual Task Tandem Gait

There was a significant interaction between group and completion time for SDS during incurring the vehicle in the lane segment (Figure 1, p=0.009). For the concussion group, the longer completion time of DT tandem gait was associated with less speed variability during incurring the vehicle in the lane segment (Table 4, B=-0.37).

3.3. Tandem Gait Dual Task Cost

Tandem gait DTC showed a significant interaction for road edge excursion (Figure 2A, p=0.030). Greater DTC in the concussion group was associated with a higher number of road edge excursions (Table 2, IRR=1.02). A similar result was found for speed variability in the residential left curve segment (Figure 2B, p=0.010, B=0.71).

3.4. Complex Figure

There were five cases where we observed significant interaction effects between group and Complex Figure copy score: Centerline crossings, road edge excursion, SDS for residential left curve, SDLP for residential right curve, and SDLP for a vehicle following task. The higher Complex Figure copy score in the concussion group was associated with fewer centerline crossings (Table 2, *p*=0.001, IRR=0.88), fewer road edge excursions (Table 2, *p*<0.001, IRR=0.84), less speed variability during the residential left curve (Figure 3B, *p*<0.001, B=-1.087), lower lane position variability during the residential right curve (Table 3, *p*=0.006, B=-0.080), and lower lane position variability during the vehicle following task (Table 3, *p*<0.001, B=-0.149).

We also found three significant interaction effects between group and Complex Figure delayed score. There was a significant interaction effect between group and Complex Figure delayed score for road edge excursions, SDLP for cross walk, and SDLP for a vehicle following task (Figure 4A). The higher Complex Figure delayed score in the concussion group was associated with a decrease in road edge excursion (Table 2, p=0.004, IRR=0.90), decreased lateral position variability for cross walk (Table 3, p=0.023, B=-0.028), and decreased lateral position variability for a vehicle following task (Table 3, p=0.009, B=-0.050). During the residential right curve, we found a significant interaction effect between group and Complex Figure delayed time for SDS (Table 4). The longer Complex Figure completion time was associated with an increased speed variability (p=0.019, B=0.007, Figure 4B).

3.5. Useful Field of View

There were no interaction effects between group and all UFOV for driving simulation outcomes (Table 2-4, all p>0.05).

3.6. Vestibular Ocular Motor Screening

While navigating to the left of a car crash, we found significant interaction effects between group and VOMS smooth pursuits, horizontal saccades, vertical saccades (Figure 5A), and horizontal VOR symptom ratings (Figure 5B) as they relate to speed variability (Table 4, all p<0.05). Higher symptom provocation in concussion group was associated with less speed variability. A similar result was found with the smooth pursuit for speed variability in cross walk segment (Table 4, p<0.001, B=-0.35).

4. Discussion

Our study shows that specific outcomes from DT tandem gait and Complex Figure assessments might be useful in clinical settings when assessing driving ability following concussion in college students. More generally speaking, our findings suggest that divided attention during tandem gait, vestibular/ocular-motor function, visuospatial attention, and visual memory may be important functions for safe driving impaired by concussion. Interestingly, and counter to our hypotheses, higher symptom provocation with VOMS was associated with less speed variability, suggesting that individuals with vestibular or oculomotor impairments may adopt more cautious or constrained driving strategies, potentially masking underlying impairments. In contrast, post-concussion symptom scores and UFOV performance appear to have limited usefulness in our sample.

4.1.1. Symptoms

We found no significant relationship between driving performance and total symptom scores for driving outcomes within the first seven days of concussion. Concussion symptoms resolve relatively quickly[11,12] while individuals still experience residual functional deficits associated with concussion. Our previous study found that symptom clusters could uniquely capture post-concussion driving impairment during the acute phase of the injury (within 72 hours).[10] These findings imply that symptom reporting may be most effective in detecting post-concussion driving impairments during the acute phase with decreased utility over time. Further study is needed to determine the effectiveness of a time frame using post-concussion symptoms to detect driving deficits following concussion.

4.1.2. Tandem Gait

We found that greater declines in DT performance relative to single-task was associated with a higher number of road edge excursions in the concussion group. This indicates that individuals with decreased divided attention ability may struggle to maintain lane position. Similarly, difficulty performing DT was associated with higher variability in speed in the residential left curve segment. Our previous study found that single-task tandem gait had limited association with driving performance in this population.[10] Driving involves multi-tasking; reacting and responding to changes in the environment, traffic signs, and other vehicles while simultaneously managing the steering wheel and acceleration. DT has been used for re-licensure for older adults.[23] More recently the DT tandem gait was added to the recommended concussion assessment protocol for sports-related concussion.[14] This study demonstrates that DT tandem gait may have the potential to be used as a metric to evaluate the extent of cognitive impairments in college students with concussion associated with driving performance.

4.1.3. Complex Figure

We found multiple associations between group and Complex Figure. The Complex Figure score of the copy trial was associated with centerline crossings and road edge excursion and the Complex Figure delayed trial score was associated with road edge excursion. We also saw that the Complex Figure copy trial score captured variability in lane positioning during the residential right curve and a vehicle following task. Also, the Complex Figure delayed trial score captured variability in lane positioning during cross walk and a vehicle following task. Greater variability of the lateral position is considered as riskier driving performance, because it is associated with poorer adjustment to changes in road parameters, increased probability of a centerline crossing or a road-edge excursion, and, ultimately, greater risk of crash.[24]

Complex Figure delayed trial time captured speed variability during a residential right curve in the concussion group, which is interesting because greater variability in speed is associated with increased odds of motor vehicle crash.[25] Contrary to our hypothesis, the longer Complex Figure copy trial time was associated with a decrease in speed variability during a vehicle following task. This may indicate that decreased visual-spatial processing promotes more cautious driving behaviors in certain situations such as a vehicle following task. These suggest that post-concussion visuospatial ability and delayed memory deficits are associated with poorer driving performance following concussion. Complex Figure takes approximately 5 minutes to complete each trial. Additional advantages of Complex Figure include being independent of auditory processing and language skills while requiring only a pen, paper, and a timer. The Complex Figure is available for clinicians to use, however, it might be less accessible in the athletic training field. Both copy and delayed trials of the Complex Figure assessment have potential value in clinical settings for evaluating driving performance in individuals with concussion.

4.1.4. UFOV

The UFOV assessment evaluates visual sensory function, visual processing speed, and visual attention; skills essential for safe driving. In older adults, poor UFOV performance is associated with an increased risk of motor vehicle crash.[26] A previous study noted that as children develop, their UFOV performance on all three subtests improves and reaches to adult level by age 14.[27] Originally UFOV was designed to assess individuals over the age of 65,[28] thus, modification might be required to be more applicable to young adults. These findings suggest that UFOV might not be as useful in college students with concussion.

4.1.5. Vestibular Ocular Motor Screening

Our results indicated that VOMS symptom provocations during smooth pursuits, horizontal saccades, vertical saccades, and horizontal VOR, are associated with SDS while navigating to the left of a car crash in the right lane in individuals with concussion. In contrast to our hypothesis, the higher symptom provocation was associated with a decrease in speed variability. A similar result was found with smooth pursuit for SDS in cross walk segment. These findings may suggest that higher symptom provocation during VOMS triggers compensatory behavior to maintain control in complex driving situations. Similar observations of decreased variability in measures of physical performance are reported after concussion during postural balance testing, hypothesized to represent a more constrained motor strategy.[29] Clinically, while VOMS does not directly measure driving skills, it may offer important insights into compensatory behavior by adopting more cautious driving strategies, potentially masking underlying impairments. VOMS, a widely used and clinically accessible tool, assesses several functions critical for locating and fixating on visual information, which is essential for safe driving.[30,31] However, the clinical implications of our findings warrant careful consideration. VOMS was associated with only 2 out of 11 segments. These findings suggest that while VOMS provides valuable information for safe driving, its use may be limited to specific and complex scenarios in post-concussion driving assessment during the first week of the injury.

4.2. Limitations

This study had limitations. We used sample of young adult college-aged students which potentially limits the generalizability of the outcomes. Even though the driving simulator has the capability to assess driving performance in a safe environment, the driving simulator does not necessarily represent real-life driving scenarios. A naturalistic driving study is needed to determine the actual driving behavior of individuals after suffering a concussion. There is missing data for some clinical assessment outcomes. There was variability in the time since concussion among participants and the range within the dataset could have influenced the results.

5. Conclusion

Our study highlights the potential utility of clinical tools for assessing driving performance in individuals who have recently sustained concussion. DT tandem gait and

Complex Figure may help identify individuals at higher risk of unsafe driving due to post-concussion deficits. These findings suggest the importance of assessing divided attention, visuospatial attention, and visual memory to inform readiness to return to driving post-concussion. While VOMS does not directly measures driving ability, it may offer insight into compensatory behavior by adapting more cautious driving strategies. Given the limited association between driving performance and UFOV and symptoms, these tools might not be effective for assessing driving ability post-concussion. These findings may inform potential strategies for facilitating recovery of these deficits enabling safer return to driving as soon as possible.

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Table 1. Descriptive and Statistical Outcomes of Participant's Characteristics and Clinical Measure Outcomes.

	Concussion (N=43)			Control (N=46)			p
Demographics							
Age	19.5 ± 1.4 years			19.5 ± 1.5 years			
Sex (Female)	26 (60.5%)			36 (76.1%)			
Time Since Concussion	3.3 ± 2.0 days						
Number of Previous Concussion	0.3 ± 0.5						
Clinical Measure Outcomes	Median	Mean	SD	Median	Mean	SD	
Symptom		N=43			N=46		
Total Symptom Score	20.00	24.08	17.76	1.50	5.28	7.28	<0.001*
DT Tandem gait		N=30			N=46		
Average Time§	20.69	22.14	6.95	19.77	19.73	4.88	0.071
DTC	36.43	42.30	26.80	28.72	34.28	36.25	0.185
VOMS		N=23			N=46		
Smooth Pursuit	0.00	0.96	2.52	0.00	-0.04	0.79	0.189
Horizontal Saccades	0.00	1.35	2.64	0.00	0.09	0.94	0.027*
Vertical Saccades	1.00	1.62	2.59	0.00	-0.02	1.13	0.030*
Near Point Convergence	0.50	0.73	4.80	0.00	0.15	1.45	0.108
Horizontal VOR	1.00	1.15	5.03	0.00	0.46	1.76	0.052
Vertical VOR	0.50	0.81	5.06	0.00	0.43	1.76	0.256
Visual Motion Sensitivity	1.50	1.46	5.25	0.00	0.76	2.02	0.063
ROCF		N=19			N=45		
Copy Score	35.00	33.80	2.85	34.00	33.60	2.65	0.287
Copy Time	113.32	122.97	42.20	117.90	113.66	29.97	0.560
Delayed Score§	24.00	23.32	4.34	23.00	22.32	6.99	0.520
Delayed Time	91.00	90.81	35.23	91.00	98.75	34.84	0.289
UFOV		N=20			N=45		
Processing Speed							
Divided Attention	33.53	37.34	21.05	36.73	36.15	11.84	0.582
Selective Attention	63.67	67.20	28.71	56.67	63.94	25.52	0.588

* Denotes significant difference. §Mann-Whitney U test was used.

DTC: Dual-Task Cost, VOR: Vestibular/Ocular Reflex, ROCF: Rey–Osterrieth Complex Figure, UFOV: Useful Field Of View

Table 2. Significant Interaction Effect (Group x Assessment) Outcome For Driving Performance.

Concussion Assessment Outcome	Full Driving Outcomes		SDLP Outcomes			SDS Outcomes					
	Centerline Crossings	Road Edge Excursions	Cross walk	Residential right curve	Vehicle following	Cross walk	Residential right curve	Residential left curve	Incurring vehicle	Vehicle cross	Vehicle following
Dual Task Tandem Gait											
Completion Time									- p=0.009, B=-0.37		
DTC		+ p=0.018, B=0.014						+ p=0.009, B=0.71			
Vestibular-Ocular Motor Screen											
Smooth Pursuit						- p<0.001, B=-0.350				- p=0.027, B=-0.340	
Horizontal Saccades										- p=0.032, B=-1.020	
Vertical Saccades										- p=0.017, B=-1.024	
Horizontal VOR										- p=0.029, B=-1.147	
Rey–Osterrieth Complex Figure											
Copy Score	+ p=0.001, B=-0.133	+ p<0.001, B=-0.174		+ p=0.006, B=-0.080	+ p<0.001, B=-0.149						
Copy Time											- p<0.001, B=-0.040
Delayed Score		+ p=0.004, B=-0.101	+ p=0.023, B=-0.028		+ p=0.009, B=-0.050						
Delayed Time							+ p=0.019, B=0.007				

(+) Driving outcome improved with better concussion assessment outcome.
(-) Driving outcome declined with better concussion assessment outcome.
SDLP: Standard Deviation of Lane Position, SDS: Standard Deviation of Speed, DTC: Dual-Task Cost, VOR: Vestibular/Ocular Reflex, IRR: Incidence Risk Ratio

Table 3. Interaction Effect (Group x Assessment) Outcome For Standard Deviation of Lane Position Outcomes.

	Standard Deviation of Lane Position Outcomes (feet/seconds)										
Concussion Assessment Outcome	Overtaking Highway	Traffic Light	Highway Left Curve	Highway Right Curve	Pedestrian Crossing	Cross walk	Residential Right Curve	Residential Left Curve	Incurring Vehicle	Vehicle Cross	Vehicle following
Symptoms											
Total Symptom Score	p=0.321	p=0.705	p=0.437	p=0.589	p=0.318	p=0.318	p=0.454	p=0.625	p=0.776	p=0.300	p=0.391
Dual Task Tandem Gait											
Completion Time	p=0.685	p=0.374	p=0.529	p=0.837	p=0.227	p=0.467	p=0.819	p=0.412	p=0.876	p=0.799	p=0.472
DTC	p=0.635	p=0.859	p=0.209	p=0.091	p=0.677	p=0.600	p=0.355	p=0.630	p=0.266	p=0.093	p=0.381
Useful Field of View											
Processing Speed	-	-	-	-	-	-	-	-	-	-	-
Divided Attention	p=0.818	p=0.434	p=0.073	p=0.094	p=0.130	p=0.076	p=0.656	p=0.732	p=0.408	p=0.223	p=0.080
Selective Attention	p=0.376	p=0.374	p=0.108	p=0.121	p=0.179	p=0.771	p=0.986	p=0.146	p=0.078	p=0.917	p=0.082
Vestibular-Ocular Motor Screen											
Smooth Pursuit	p=0.591	p=0.714	p=0.160	p=0.072	p=0.134	p=0.614	p=0.173	p=0.911	p=0.111	p=0.171	p=0.436
Horizontal Saccades	p=0.604	p=0.554	p=0.638	p=0.279	p=0.357	p=0.743	p=0.529	p=0.531	p=0.854	p=0.141	p=0.387
Vertical Saccades	p=0.354	p=0.141	p=0.485	p=0.366	p=0.214	p=0.743	p=0.125	p=0.960	p=0.235	p=0.715	p=0.925
Near Point Convergence	p=0.439	p=0.982	p=0.297	p=0.598	p=0.157	p=0.861	p=0.961	p=0.762	p=0.495	p=0.462	p=0.578
Horizontal VOR	p=0.654	p=0.714	p=0.399	p=0.791	p=0.169	p=0.927	p=0.750	p=0.759	p=0.308	p=0.530	p=0.644
Vertical VOR	p=0.328	p=0.578	p=0.860	p=0.626	p=0.110	p=0.806	p=0.909	p=0.711	p=0.163	p=0.590	p=0.741
Visual Motion Sensitivity	p=0.159	p=0.118	p=0.559	p=0.505	p=0.124	p=0.750	p=0.670	p=0.677	p=0.183	p=0.331	p=0.975
Rey–Osterrieth Complex Figure											
Copy Score	p=0.748	p=0.773	p=0.918	p=0.209	p=0.359	p=0.145	+ **p=0.006,β=-0.080 95CI: -0.03~ -0.13**	p=0.160	p=0.199	p=0.315	+ **p<0.001, β=-0.149 95%CI: -0.1~ -0.2**
Copy Time	p=0.393	p=0.265	p=0.836	p=0.093	p=0.559	p=0.146	p=0.481	p=0.553	p=0.074	p=0.524	p=0.324
Delayed Score	p=0.355	p=0.967	p=0.927	p=0.964	p=0.260	+ **p=0.023, β=-0.028 95%CI:-0.00~ -0.06**	p=0.954	p=0.823	p=0.305	p=0.252	+ **p=0.009, β=-0.050 95%CI:-0.01~ -0.09**
Delayed Time	p=0.383	p=0.921	p=0.780	p=0.924	p=0.635	p=0.387	p=0.523	p=0.476	p=0.789	p=0.447	p=0.208

(+) Driving outcome improved with better concussion assessment outcome.
(-) Driving outcome declined with better concussion assessment outcome.
DTC: Dual-Task Cost, VOR: Vestibular/Ocular Reflex, IRR: Incidence Risk Ratio
- Model failed to converge.

Table 4. Interaction Effect (Group x Assessment) Outcome For Standard Deviation of Speed Outcomes.

Concussion Assessment Outcome	Standard Deviation of Speed Outcomes (feet/seconds)										
	Overtaking Highway	Traffic Light	Highway Left Curve	Highway Right Curve	Pedestrian Crossing	Cross walk	Residential Right Curve	Residential Left Curve	Incurring Vehicle	Vehicle Cross	Vehicle following
Symptoms											
Total Symptom Score	p=0.353	p=0.238	p=0.078	p=0.066	p=0.084	p=0.098	p=0.900	p=0.171	p=0.470	p=0.421	p=0.845
Dual Task Tandem Gait											
Completion Time	p=0.632	p=0.981	p=0.873	p=0.057	p=0.943	p=0.876	p=0.928	p=0.877	(-) **p=0.009, β=-0.37 95%CI: -0.07~ -0.01**	p=0.807	p=0.080
DTC	p=0.788	p=0.653	p=0.591	p=0.100	p=0.396	p=0.705	p=0.247	(+) **p=0.009, β=0.71 95%CI: 0.02-0.12**	p=0.714	p=0.608	p=0.729
Useful Field of View											
Processing Speed	-	-	-	-	-	-	-	-	-	-	-
Divided Attention	p=0.796	p=0.642	p=0.142	p=0.884	p=0.797	p=0.258	p=0.621	p=0.844	p=0.560	p=0.407	p=0.915
Selective Attention	p=0.535	p=0.293	p=0.903	p=0.054	p=0.232	p=0.361	p=0.592	p=0.360	p=0.881	p=0.662	p=0.359
Vestibular-Ocular Motor Screen											
Smooth Pursuit	p=0.868	p=0.601	p=0.513	p=0.794	p=0.407	(-) **p<0.001, β=-0.350 95%CI: -0.06~ -0.01**	p=0.332	p=0.728	p=0.448	(-) **p=0.027, β=-0.340 95%CI: -0.06~ -0.01**	p=0.434
Horizontal Saccades	p=0.698	p=0.948	p=0.064	p=0.837	p=0.244	p=0.290	p=0.793	p=0.736	p=0.244	(-) **p=0.032, β=-1.020 95%CI: -1.81~ -0.23**	p=0.977
Vertical Saccades	p=0.776	p=0.825	p=0.860	p=0.889	p=0.648	p=0.217	p=0.867	p=0.824	p=0.725	(-) **p=0.017, β=-1.024 95%CI: -1.93~ -0.11**	p=0.586
Near Point Convergence	p=0.873	p=0.557	p=0.243	p=0.828	p=0.192	p=0.186	p=0.728	p=0.695	p=0.207	p=0.167	p=0.344
Horizontal VOR	p=0.575	p=0.589	p=0.375	p=0.982	p=0.245	p=0.419	p=0.149	p=0.811	p=0.357	(-) **p=0.029, β=-1.147 95%CI: -1.95~ -0.34**	p=0.307
Vertical VOR	p=0.685	p=0.309	p=0.086	p=0.899	p=0.201	p=0.513	p=0.838	p=0.708	p=0.664	p=0.136	p=0.729
Visual Motion Sensitivity	p=0.508	p=0.505	p=0.491	p=0.872	p=0.631	p=0.426	p=0.371	p=0.922	p=0.826	p=0.384	p=0.961
Rey–Osterrieth Complex Figure											
Copy Score	p=0.306	p=0.457	p=0.096	p=0.631	p=0.093	p=0.899	p=0.229	(-) **p<0.001, β=-1.087 95%CI: -1.65~ -0.53**	p=0.874	p=0.118	p=0.177
Copy Time	p=0.199	p=0.487	p=0.800	p=0.372	p=0.555	p=0.156	p=0.206	p=0.284	p=0.081	p=0.762	(-) **p<0.001, β=-0.040 95%CI: -0.006~ -0.001**
Delayed Score	p=0.269	p=0.337	p=0.892	p=0.912	p=0.543	p=0.344	p=0.405	p=0.127	p=0.575	p=0.434	p=0.224
Delayed Time	p=0.258	p=0.061	p=0.409	p=0.717	p=0.447	p=0.801	(+) **p=0.019, β=0.007 95%CI: 0.001-0.014**	p=0.652	p=0.807	p=0.692	p=0.813

(+) Driving outcome improved with better concussion assessment outcome.
(-) Driving outcome declined with better concussion assessment outcome.
DTC: Dual-Task Cost, VOR: Vestibular/Ocular Reflex, IRR: Incidence Risk Ratio
 - Model failed to converge.

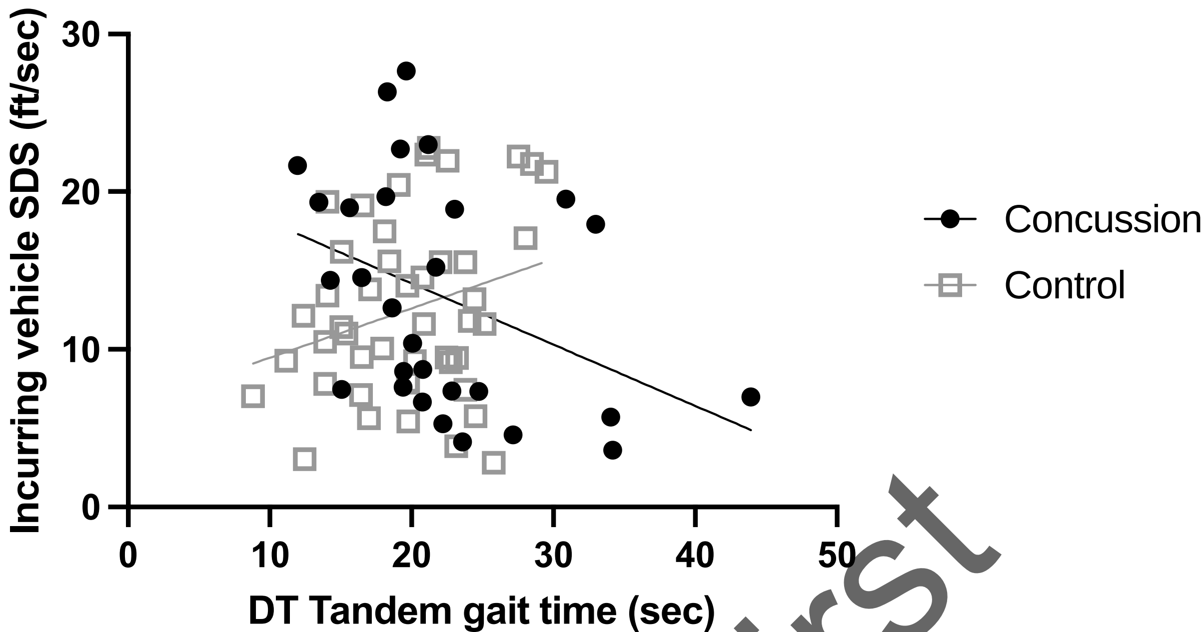

Figure 1. Interaction between group and DT tandem gait completion time for SDS during incurring vehicle in the lane.
SDS: Standard Deviation of Speed, DT: Dual-Task

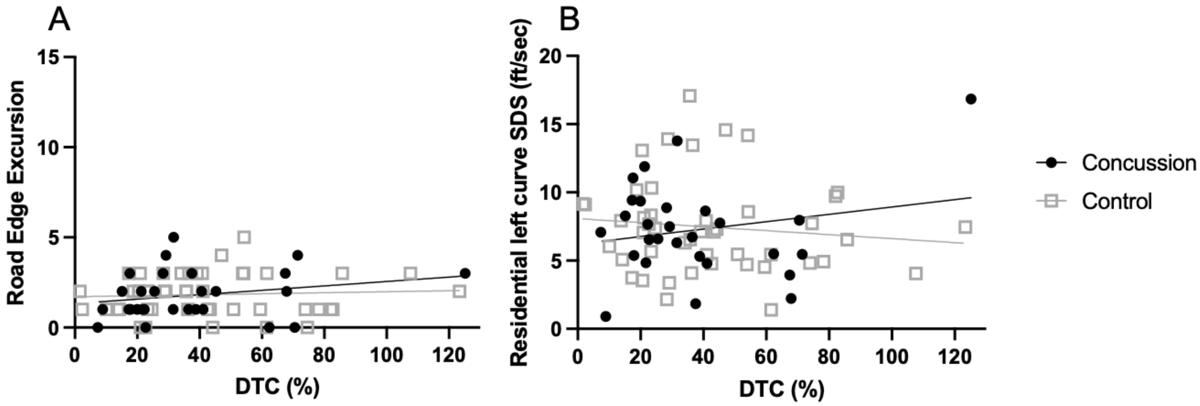

Figure 2. Interactions between group and DT tandem gait completion time for A) SDS during resident left curve and B) road edge excursion.
SDS: Standard Deviation of Speed, DTC: Dual-Task Cost.

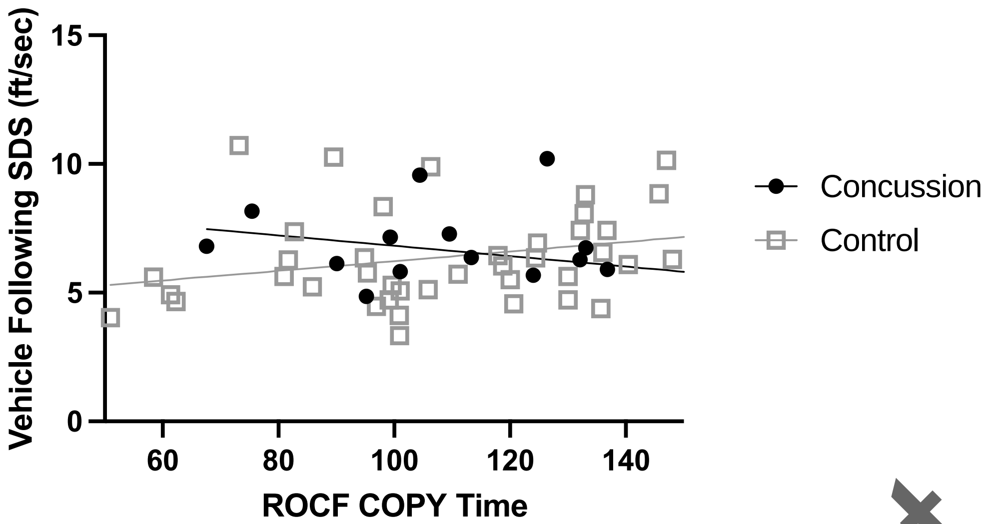

Figure 3. Interaction between group and ROCF Copy Time for SDS during vehicle following.
SDS: Standard Deviation of Speed, ROCF: Rey–Osterrieth Complex Figure.

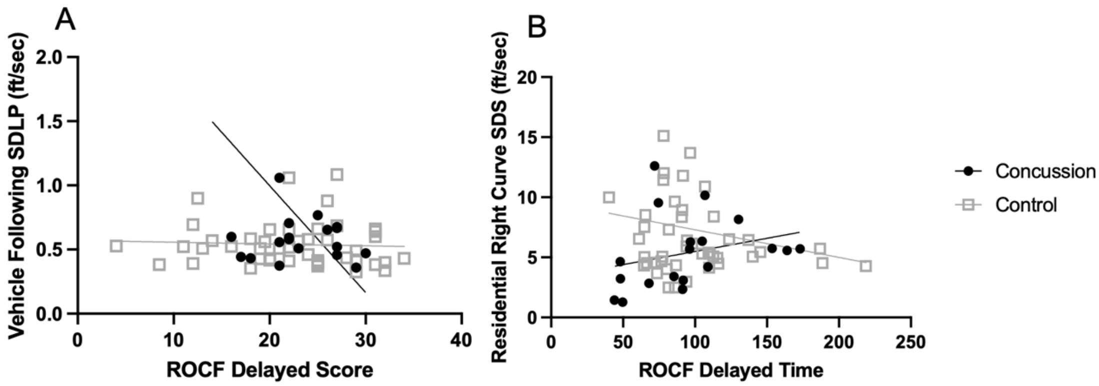

Figure 4. A) Interaction between group and ROCF Delayed Score for SDLP during vehicle following and B) interactions between group and ROCF Delayed Time for SDS during resident right curve.
SDS: Standard Deviation of Speed, SDLP: Standard Deviation of Lane Position, ROCF: Rey–Osterrieth Complex Figure.

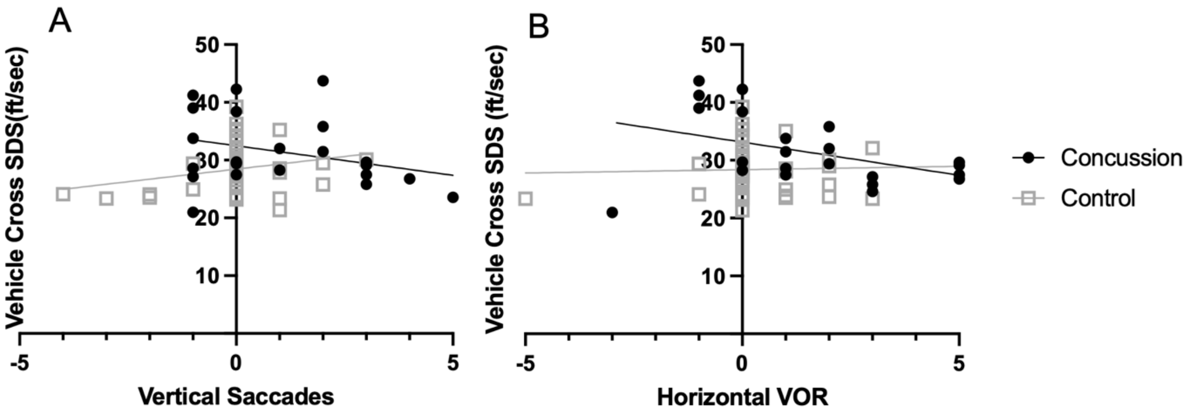

Figure 5. Interactions between group and A) vertical saccades and B) horizontal VOR for SDS during vehicle cross.
SDS: Standard Deviation of Speed, VOR: Vestibular/Ocular Reflex.