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Alcohol Intoxication Checklist: A Naturalistic Approach

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ABSTRACT

This effort sought to determine the prevalence of particular visual and behavioral indicators for alcohol intoxication using data collected in the Strategic Highway Research Program 2 Naturalistic Driving Study (SHRP 2 NDS). A list of visual and behavioral cues was identified from previous research and served as the basis for identification. The prevalence of several of these cues reached statistical significance between judged states of intoxication. Some cues include, but are not limited to, lids-heavy, dozing, exhilarated, distracted, talkative, inability to sit upright, yawning, and leaning against window. While the study was able to determine the prevalence of the markers, several limitations temper interpretation. First, a large proportion of trips evaluated occurred between midnight and 4:00 a.m., when drivers are likely to be drowsy and exhibit many of the same visual and behavioral indicators also expected to be present in intoxicated individuals. Thus, impacts of drowsiness may be confounded with those of intoxication. In addition, the same visual cues were used both to determine the degree of intoxication as well as the behaviors most associated thereto, thus resulting in a logical conundrum. The results of this research should be viewed as exploratory work that can aid in the generation of hypotheses for future work.

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LIST OF ABBREVIATIONS AND SYMBOLS

BAC	blood alcohol concentration
CAN	Controller Area Network
DAS	data acquisition system
DWI	driving while intoxicated
ER	emergency room
IRB	institutional review board
FARS	Fatality Analysis Reporting System
FET	Fisher’s Exact Test
HGN	horizontal gaze nystagmus
NDS	naturalistic driving study
SHRP 2	Second Strategic Highway Research Program

CHAPTER 1. INTRODUCTION

PROBLEM STATEMENT

Driving while intoxicated (DWI) by alcohol remains a serious traffic safety concern. The percentage of traffic fatalities with a driver presenting a blood alcohol concentration (BAC) over 0.08 has remained relatively steady over the last 10 years at around 29%. In 2018, this resulted in 10,511 individuals who died in crashes with an alcohol-impaired driver (National Center for Statistics and Analysis, 2019).

One way to better comprehend and prevent intoxicated driving, and the crashes it can lead to, is to identify visual or behavioral signs of alcohol intoxication in the absence of a breathalyzer or other definitive source of information. Visual identification of intoxicated drivers may be beneficial to law enforcement officers both from a distance (i.e., identifying characteristic vehicle movements) and at close proximity (i.e., observing characteristic driver behaviors just prior to or during a traffic stop), as well as for those who interact with the public such as bartenders or wait staff. Another potentially important outcome may be the ability for researchers to identify alcohol intoxication via recorded video in naturalistic driving studies (NDS). The current effort explores a novel area: the application of previous research on visual and behavioral identifiers of intoxication to NDS video views of the driver's face and key measures of vehicle kinematics. The literature review presented below discusses relevant previous efforts to identify intoxication in different contexts in order to determine which identifiers could be applicable to the current undertaking.

LITERATURE REVIEW

Evidence of exhilaration, such as strong excitement or happiness beyond what would typically be expected, as a sign of alcohol intoxication has been shown in emergency room (ER) work (Cherpitel et al., 2005). The imbibing of alcohol has been shown to increase feelings of exhilaration among participants in a laboratory setting (Sutker et al., 1983).

Between 2005 and 2009 a 63% increase in fatal crashes was found when evaluating distracted driving among those who were *also* intoxicated, indicating that intoxicated drivers may be more likely to engage in a secondary task. The role of alcohol in distracted crashes accounted for 32% of deaths from distraction (Wilson et al., 2013). Meanwhile, intoxicated participants in a driving simulator were shown to be less attentive to external stimuli and have a weaker response to novel sounds when engaged in a secondary task than sober participants, indicating that intoxicated drivers may be less adept at multi-tasking (Rakauskas et al., 2005).

Alcohol has also been shown to reduce social inhibitions, thereby increasing verbal disclosure and making participants more verbose overall, albeit with mixed results in forced social situations (Caudill et al., 1987; Monahan & Lannutti, 2000). In social situations where participants were encouraged to talk with an attractive confederate, some women experienced reduced anxiety and increased talkativeness after imbibing alcohol; however, other women did not, with the mediating factor seeming to be socioeconomic status (Monahan & Lannutti, 2000). Other work showed increased openness, but only for men (Caudill et al., 1987).

Modig et al. (2012) showed that intoxicated individuals have poorer postural control. In laboratory settings, dosed participants stood on an oscillating platform where balance was tested (both lateral and posterior-anterior). Alcohol was shown to promote dose-dependent postural control degradations in a balance task with greater effects on lateral postural control. Varying effects were noted, including whether the platform oscillated or not, whether eyes were open or not, and different planes of measurement along body axes (i.e., fore-aft or side-to-side).

Cues Visible in Social Drinking

Visual and behavioral intoxication cues have been utilized in training for waitstaff, bar tenders, and managers who work in locations that serve alcohol (McKnight, 1991). This work provided training on responsible alcohol service to servers and managers in several different establishments throughout the United States. Training materials focused on identifiers such as sweaty or flushed face, glassy eyes, nauseous behaviors, drowsiness, clumsiness or fumbling, and unsteadiness. Researchers then recorded staff behavior in terms of whether alcohol service was denied or not to actors feigning intoxication. Trained servers were statistically more likely to discourage drinking and/or outright refuse continued service to researchers acting out the signs of intoxication compared to servers without the specialized training. Wait staff were more likely to discourage continued drinking and more likely to outright refuse service compared to pre-intervention. This study focused primarily on visual and behavioral identifiers identifiable by wait staff. While many cues tested in this study are useful to in-person intoxication detection for wait staff (loud or slurred speech, forgetfulness, domineering behaviors, and exhibition of being withdrawn), they are not so for the purpose of naturalistic data analysis because they rely on specific social/vocal interactions with the observer. However, additional identifiers from this study that may prove useful to the current effort and that are visible in NDS video include a sweaty or flushed face, glassy eyes, nauseous behaviors, drowsiness, clumsiness or fumbling, and unsteadiness.

Applying several visual and behavioral cues, trained observers evaluated the level of alcohol intoxication of 149 participants (McKnight & Marques, 1990). Participants were invited to drink as much alcohol as desired up to a maximum BAC of 0.12. Observers were responsible for noting the presence of 166 different cues (derived from a literature review, focus group, and observations of non-participants in bars and restaurants in different cities) and estimating an individual's BAC category without the direct knowledge of a participant's alcohol intake. Example cues included yawning; elation; red, bloodshot eyes; leaning on walls or other objects for minor support; and confusion. In all, the authors identified 31 cues with a correlation to breathalyzer BAC results. Results were highest when observers used three BAC categories to estimate intoxication levels: 0.0 to 0.04, 0.04 to 0.08, and over 0.08. In the three-level estimation approach, observers correctly estimated BAC in 53% of cases. Several of the cues evaluated are readily visible in NDS face video.

Counter to the research presented above, other studies have shown the lack of reliability among visual and behavioral indicators of alcohol intoxication. Rubenzer (2011) surveyed the literature to determine the viability of several identifiers used to indicate intoxication. The review noted a variety of cues, but many may be impossible to determine from an in-vehicle camera and without audio. The authors noted that the review found no reliable visual or behavioral cues that would typically be visible in an NDS (e.g., red face, sweating, red eyes, poor posture) at lower levels of intoxication, likely due to large individual differences and a wide variety of tolerance levels between casual and frequent heavy drinkers. The results of the study concluded that judging low to moderate levels of intoxication with visual and behavioral identifiers is a very difficult task.

Similarly, McKnight and colleagues (2002) developed a series of assessments and visual cues that relate to alcohol intoxication. Cues evaluated included heat measures such as excessive sweating, or red face or eyes. Reliable correlations between BAC and specific cues were present for measures including a red face, sweaty face, and red eyes during the development of the protocol (using BAC levels up to 0.12). The authors continued testing to determine the validity of several cues at detecting lower BAC levels. The only identifier noted to be valid was horizontal gaze nystagmus (HGN) for alcohol detection between people above and below a BAC of 0.04, suggesting that facial heat measures (sweating, red face, red eyes, and flushed face) are not sensitive enough to determine intoxication at a low BAC given large individual differences in the manifestation of alcohol intoxication (McKnight et al., 2002). As HGN cannot be utilized in the context of a video reduction in an NDS, the facial cues noted in higher BAC levels were utilized.

Vehicular Control Factors

Harris et al. (1980) showed an increase in driving while intoxicated arrests following a training program developed for police officers. The detection protocol included several vehicular control cues, such as turning with a wide radius, straddling the center line or marker, weaving, swerving, drifting, and braking erratically. In total, 20 vehicular control cues were utilized by officers to identify intoxicated drivers. Identifiers were validated by field test results, which showed that breathalyzer results correlated significantly with estimated BAC levels associated with individual cues. This work focused on identifiers that would be visible from the perspective of a police officer, but several of these cues may be equally visible in an NDS as well, where forward video, and acceleration, braking, and steering data are captured. Using Harris et al.'s (1980) work as a springboard, another study attempted to use the cues to increase driving while intoxicated (DWI) arrests in a city in southern Ontario (Vingilis et al., 1983). Results showed a lower overall prevalence of behaviors from those who experienced the training protocol discussed earlier; still, notable levels of swerving, drifting, and weaving remained. There was a significant increase in DWI arrests after program implementation.

Additionally, in driving simulators, participants with a higher BAC performed poorer than sober participants on several driving metrics, including speed variability and the number of run-off-road events (Arnedt et al., 2001; Liu & Ho, 2010). Other work showed that sober participants performed lane maintenance tasks better than intoxicated participants (Huemer & Vollrath, 2010; Weafer et al., 2008). A technology-based solution utilized lane- and vehicle-control metrics, including weaving, drifting, swerving, and turning with a wide radius to develop an experimental app. Users can install the app on their phone, which will identify intoxicated driving based on the kinematic inputs (Dai et al., 2010). A cursory search of the application marketspace does not show any current implementations of vehicle kinematics or smartphone kinematics to identify intoxicated driving.

OBJECTIVES

Given the established research on visual and behavioral indicators of alcohol intoxication outlined above, several potential cues may prove useful in helping to identify alcohol intoxication. The goal of this effort is to determine the prevalence of a set of visual and behavioral alcohol intoxication cues in the naturalistic driving data, specifically the video data, collected by the Second Strategic Highway Research Program (SHRP 2) NDS and determine how they vary relative to ratings of intoxication. The potential use of such cues may prove valuable for naturalistic driving research where video views of participants and the surrounding roadway are available but no breathalyzer or other definitive source of intoxication levels is present.

CHAPTER 2. METHOD

This research was approved by the Virginia Tech Institutional Review Board (IRB) as IRB-15-888. A data use license (DUL) was also completed in order to access the data collected during the SHRP 2 NDS, the largest video-based NDS completed to date. The SHRP 2 NDS database contains data collected from 3,645 participants for up to 2 years per participant. Participants were between 16 and 98 years old. All data were collected between 2010 and 2013, resulting in a total of over 30 million miles of driving data. Participants lived near one of six sites across the United States: Buffalo, New York; Tampa, Florida; Seattle, Washington; Durham, North Carolina; Bloomington, Indiana; and State College, Pennsylvania. The installed data acquisition system (DAS) collected data from four camera views at 10 Hz (face, forward, hands, and rear; Figure 1) and from multiple sensors, including radar, gyroscope, accelerometers, GPS, and vehicle network data from the Controller Area Network (CAN). The hardware was designed to be as unobtrusive as possible (Figure 2). Further details of the study and methodology are presented in Antin et al. (2019).

Figure 1. Photo. SHRP 2 NDS type video views showing forward, face, hands, and rear camera views (non-participant shown in photo).

Figure 2. Photos. SHRP 2 NDS DAS installation showing head unit located behind the rearview mirror (left) and the main unit mounted to top of trunk (right).

ALCOHOL SENSOR

An alcohol sensor embedded in the head unit (mounted behind the rear-view mirror) recorded the presence of alcohol in the ambient air of the vehicle cabin. The sensor was an HS130D from Sencera Co., Ltd, a tin dioxide semiconductor gas sensor. It measures the presence of ethanol in the air and registers a response from an individual who is currently consuming alcohol or an individual who has recently consumed alcohol but who is not currently doing so. The sensor also registers the presence of other non-imbibed sources such as hand sanitizer, perfume, or mouthwash. Figure 3 shows different outputs of the alcohol sensor based on the triggering substance, while Figure 4 shows the output for the presence of imbibed alcohol. The presence of alcohol is indicated by a drop in millivolts (mV).

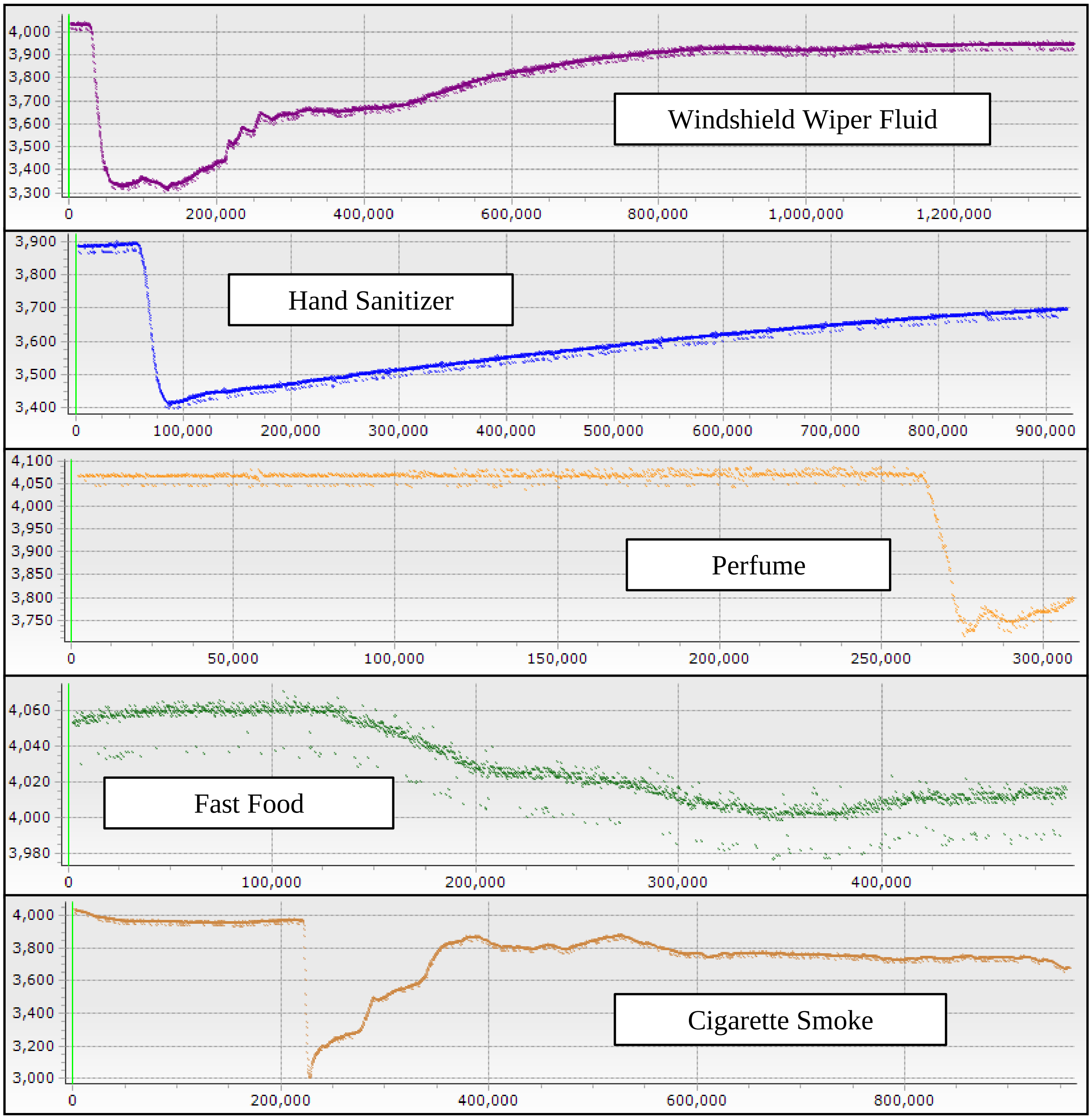

Figure 3. Graphs. Alcohol sensor traces for different activating substances (from Smith et al., 2015).

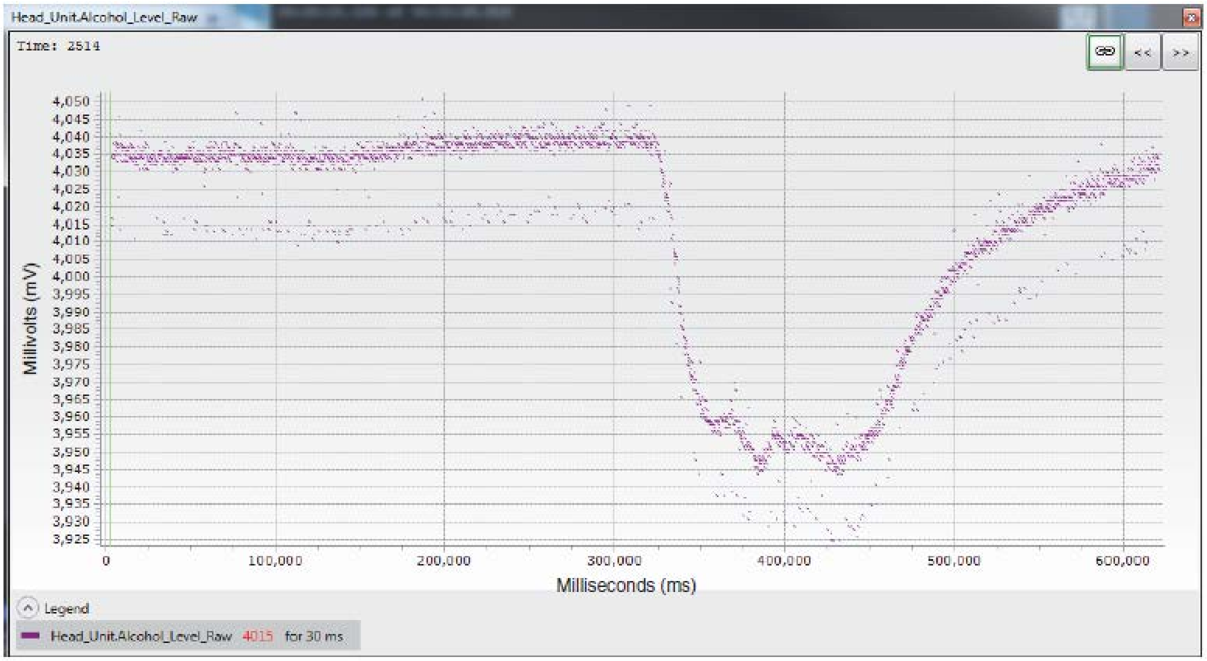

Figure 4. Graph. Alcohol sensor trace for imbibed alcohol (from Smith et al., 2015).

NATURALISTIC APPROACH

It was important to make sure the sample had an adequate number of "likely positives" where imbibed alcohol was likely present to determine the presence of behavioral and visual cues, as well as a control group where alcohol presence, though possible, was unlikely. Since the true number of impaired drivers in the SHRP 2 NDS database was unknown and could be rare, a sampling strategy was used to try to maximize the number of trips that would include impaired individuals.

The SHRP 2 NDS trips provided to the data reduction team were carefully selected. These procedures are described in greater detail below. Note that for this effort, trips are defined as the time from key-on to key-off, minus approximately 30 seconds of DAS start-up time after key-on. All analyses completed for this research effort made use of the entire trip duration to identify the possible presence of non-imbibed and/or imbibed alcohol.

Selection of SHRP 2 NDS Trip Files

Two batches of trips were selected for evaluation: the first targeted likely presence of imbibed alcohol, and the second targeted likely absence of imbibed alcohol. All trips selected for the first batch occurred between 12:00 a.m. and 4:00 a.m. local time, a time range with an increased likelihood of imbibed alcohol presence. Additionally, trips for the first batch were also selected based on alcohol sensor values to maximize the probability of finding impaired trips. The following additional points guided the first trip selection process (Smith et al., 2015):

- A moving average was utilized to address the presence of a *shadow* by removing all points that deviated strongly from the average. The *shadow* refers to an additional alcohol sensor trace (in the same trip) which follows the pattern of the sensor readings but with lower output voltages. See the “fast food” example in Figure 3, where there is a clear data trace showing voltage ratings over time, but corresponding lower values are also present and follow the same overall pattern. The resulting cleaned signal was then utilized to locate potential trips of interest.

- The value of sensor readings was shown to be related to the presence of imbibed alcohol. A threshold of 3,965 mV was utilized for this effort; any trip with an average value below this level was included. Recall that lower voltage levels indicate greater concentration of alcohol in the cabin.
- There is variance in the amount of time required for the alcohol sensor to accurately detect the presence of alcohol. For the purposes of trip selection, a warm-up period of 50 seconds was set and resulted in this data from sample qualification. This facilitated the process of ensuring that short trips were not needlessly discarded while removing some of the potentially invalid warm-up readings that may occur at the beginning of trip files.

Finally, a small number of sampled trips were ultimately excluded from the reduction process if they failed the initial data ingestion quality assurance process required for any SHRP 2 NDS trip, if the consented driver was not present for the trip, or if the video views and/or alcohol sensor data were corrupted so as to prevent reviewing of the data. This process resulted in 33 trips being removed from the sampled dataset.

The first batch of trips with potential intoxication was identified via the alcohol sensor readings, yielding 635 trips. A second batch was chosen at random, irrespective of time of day or sensor readings. This was done in order to include trips during which imbibed alcohol presence was unlikely. While the first batch of trips helped to accomplish the objective of exploring trips with a higher likelihood of alcohol intoxication, the second batch of trips (n = 387) accomplished the objective of evaluating additional trips that were more likely to be representative of the overall SHRP 2 NDS dataset (Figure 5). Recall that alcohol sensor values were only utilized to help determine trip selection in the first batch, not to assign intoxication levels nor to assess analysts’ intoxication ratings. This final combined sample of 1,022 trips served as the naturalistic dataset for the work reported here.

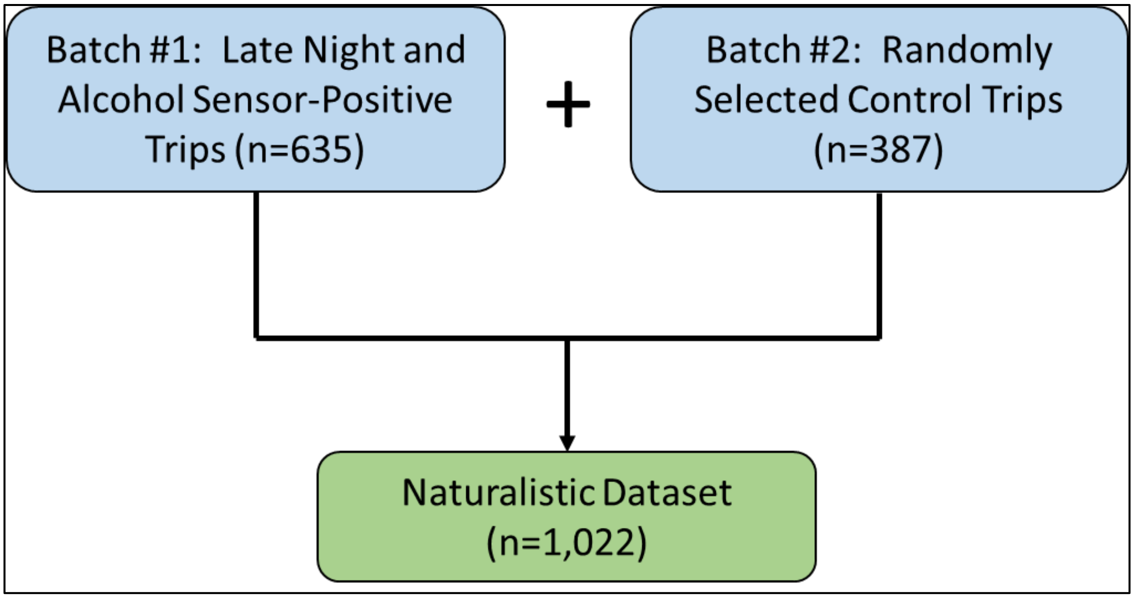

Figure 5. Diagram. Selection of SHRP 2 NDS trips resulting in final naturalistic dataset.

Alcohol Impairment Behavioral Checklist

Significant effort went into the development of a behavioral checklist for alcohol impairment using visual and behavioral cues that would be identifiable using the SHRP 2 NDS cameras. By starting with over 94 cues discussed in the literature (Harris et al., 1980; McKnight, 1991; McKnight et al., 2002; McKnight & Marques, 1990; Rubenzer, 2011), the research team produced a checklist of 64 cues that were potentially observable in the SHRP 2 NDS video. These 64 cues fit into 15 feature types (such as “eyes” or “mood”) and were then collapsed into four broad categories: appearance, affective, motor, and vehicular signs (Figure 6).

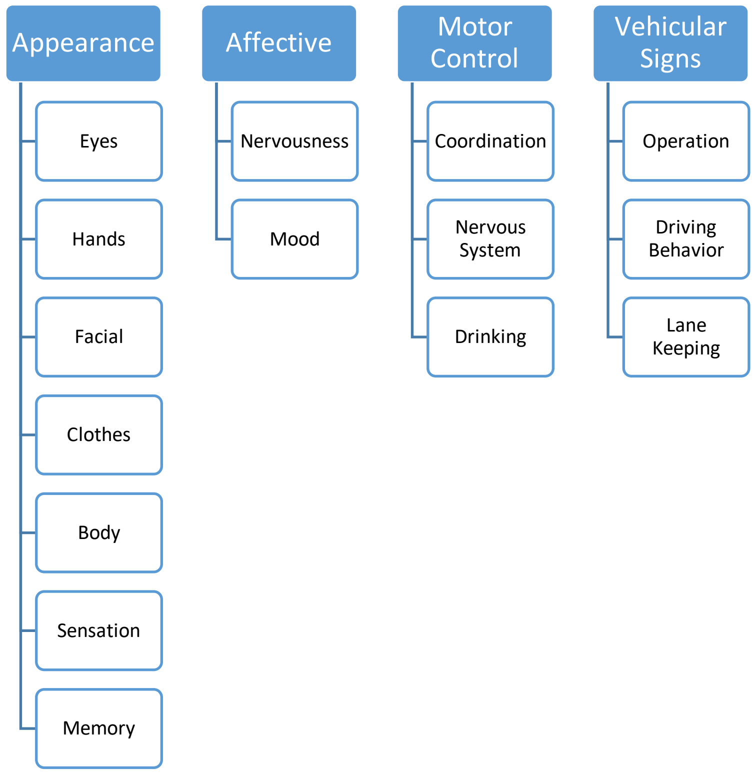

Figure 6. Diagram. Types of visual and behavioral cues assessed.

The operational definitions for the various visual and behavioral cues making up the broad category of "appearance" are presented in Table 1. Appearance includes visual signs of heat and eye-based cues, evidence of impaired memory, disheveled looks, and other behaviors.

Table 1. Operational definitions for appearance-based visual and behavioral cues.

Feature Type	Cue/Behavior	Manifesting Observations
1. Eyes	Blinking (flitting)	• rapid blinking • excessively frequent blinking
	Lids-heavy	• prolonged, slow blinks • drooping eyelids • eyes half shut
	Dozing	• similar to "nodding off" • eyes completely shut for prolonged periods of time • head drops and jerks back up
2. Hands	Shaking	• hands twitching/shaking • hands unsteady
3. Face	Flushed	• face is red • face is blotchy or has dark spots on cheeks
	Sweating	• beads of sweat on face • hair appears wet
	Drooling	• saliva appears around mouth • drool may run down face • driver frequently wipes mouth

Feature Type	Cue/Behavior	Manifesting Observations
4. Hair	Disheveled	• hair disorganized/not neat • hair sticking up or ruffled
5. Clothing	Shirt unkempt	• shirt partially untucked • shirt wrinkled excessively • shirt buttoned incorrectly • collar turned up or partially turned up • shirt generally fitting or being worn improperly
	Loosening/Taking Off	• shirt unbuttoned or partially buttoned • sleeves rolled up • untucking or loosening shirt • removing articles of clothing • missing articles of clothing
6. Involuntary Behaviors	Body Tremors/Shaking	• body is shaking uncontrollably • slight shaking of the body • body is experiencing tremors
	Dizziness	• the sensation of disequilibrium - lightheadedness, faintness, or unsteadiness • body appears to be uncontrolled • head "spinning" • body leaning to one side or not upright • body leaning against window or swaying back and forth
	Nauseous	• driver appears to be on the verge of getting sick • may make motion as if to vomit or gag • covers mouth with hand indicating the potential to vomit/vomits • face appears sick
7. Rubbing Head or Face	Rubbing head (like for a headache)	• driver is using hands to rub face or temples to signify a headache • massages temples, face, or back of neck
	Rubbing face	• rubs face for a second or more - does not include brushing objects off face
8. Memory	Repetitive Action	• engages in any repetitive action - playing with hair, adjusting clothing, rubbing eyes, etc.
	Gets Lost	• looks around as if not knowing where s/he is

Table 2 shows the operational definitions for the "affective" category of cues, which encompasses a range of emotional cues.

Table 2. Operational definitions for affective visual and behavioral cues.

Category	Cue/Behavior	Manifesting Observations
9. Nervousness	Nervous	• driver looks uncomfortable or nervous
	Restless	• driver seems fidgety • frequent movements • may seem uncomfortable
	Agitated	• appears annoyed • may seem short with passengers • driver may display frustrated facial emotions or give rude hand gestures
	Relaxed	• driver appears overly calm
10. Mood	Crying	• face wet from tears • wipes eyes
	Exhilarated	• driver seems full of energy • bouncing in seat • drumming on steering wheel • singing • dancing in seat
	Rapid changes in mood	• driver experiences a multitude of emotions in a very short period • emotions quickly fluctuating
	Hostile	• angry expression on driver's face • driver makes rude or aggressive gestures • driver appears to be yelling • driver is forceful with gestures
	Distracted	• not paying attention to the road • excessively looking around, in, and/or outside of the vehicle
	Extremely friendly	• driver may appear overly talkative • excessive or exaggerated hand gestures • have an unusually open body posture
	Talkative	• driver is constantly talking
	Sexually aggressive	• excessive touching • forced contact • strong sexual gestures.
	Confused	• driver does not appear to know what is going on or where s/he is • confused look on face • looking around as if to gain clues

Visual and behavioral identifiers for the "motor control" category of cues as they relate to coordination or the nervous system are presented along with associated operational definitions in Table 3.

Table 3. Operational definitions for motor control visual and behavioral cues.

Category	Cue/Behavior	Manifesting Observations
11. Coordination	Posture: cannot sit up straight	• slumped in seat • leaning to one side of seat • driver attempts to sit up straight but fails
	Drops/spills/knocks things over	• attempts to reach for something and instead knocks it over • while holding something, drops it without intent
12. Nervous System	Hiccups	• throat constricting • shoulders abruptly moving up and then down
	Belching	• mouth open, head moving forward
	Vomiting	• throwing up
	Seizures, convulsions	• violent jerking motions of entire body
	Asleep	• eyes completely closed with body relaxed
	Breathing fast	• frequent and quick rising and dropping of chest and/or shoulders
	Yawning	• prolonged wide-open mouth
	Stupor	• driver has blank glance • appears “zoned out” • not paying attention to surroundings • steady forward gaze without focusing eyes or scanning driving scene

Additionally, analyst judgements of vehicle kinematics were used as identifiers of possible intoxication. These were sorted into three broad categories: operational control, driving behavior, and lane keeping (Table 4).

Table 4. Vehicle and kinematic cues.

Category	Cue/Behavior
11. Operation	Stopping inappropriately
	Turning abruptly or illegally
	Swerving
	Accelerating or decelerating rapidly
	Almost striking object or vehicle
	Slow speed
	Fast speed
	Breaking erratically
	Headlights off
12. Driving Behavior	Appearing to drive drunkenly
	Driving, not on roadway
	Following too close
	Vehicle defects
	Slow response signals
	Improper signal
13. Lane Keeping	Tires on center line or marker
	Straddling center line or marker
	Drifting
	Turning with wide radius
	Driving in opposing lane

Data Reduction Procedure

Five analysts applied data reduction protocols to the selected trip files. These individuals all had prior research experience working with projects in the alcohol intoxication domain. Furthermore, each was trained specifically for this project by a data reduction supervisor.

In addition to the alcohol sensor and the kinematic sensors, the camera views that were part of the standard SHRP 2 NDS instrumentation package provided a reliable method for determining intoxication cues. Camera views captured the forward roadway, rearward roadway, driver's face, and driver's hands. Analysts looked at all camera views to gauge impairment. They checked for and coded signs of impairment across several broad categories which included seeing alcohol sources within a vehicle (both imbibed and non-imbibed), the visual and behavioral cues listed in Tables 1 through 3 above from the face-view camera, and vehicular control. Analysts observed and coded these categories of cues and were then asked to make subjective evaluations of driver impairment (impaired, unimpaired, may be impaired) and degree of impairment (1–10, with 10 being the highest level of impairment) based on their overall impressions of the driver. Analysts also coded signs of, or the presence of, non-imbibed alcohol sources. A list of known alcohol-sensor triggers was provided, including fast food, hand sanitizer, perfume, cologne, cigarettes, marijuana, other drugs, chewing gum, and windshield wiper fluid. The option was available to also note the presence of any other substance that may have affected the alcohol sensor. Analysts were encouraged to examine all video views of the data but did not examine alcohol sensor readings. Trips from the two samples were pooled together and presented in a random order so that the analysts were blind to sample type. No further analysis was performed using the alcohol sensor readings. Each video took approximately 10 to 15 minutes to code. For longer trips, the data reductionists were instructed to watch at minimum the first 1 minute, last 1 minute, and five to six 30-second intervals at random points between. Additionally, analysts were instructed to scan the entire trip at increased playback speed to find possible sources of non-imbibed alcohol and identify critical events that could be particularly informative in making judgments of impairment.

CHAPTER 3. RESULTS

Chi square analyses were conducted. In instances where more than one cell contained fewer than five data points, a Fisher's Exact Test (FET) was utilized. In the tables below, bolded entries indicate statistical significance. Many testing and *p*-value cells are blank due to a low prevalence of identifiers. In these cases, no inferential testing was conducted; however, prevalence was still reported where applicable. The results are grouped based on the similarity of cues evaluated. Again, note that for judgements of alcohol intoxication, these categories depict the analysts' subjective evaluation of intoxication based on visual cues, not an assessment of intoxication based on alcohol sensor values.

EYES

Table 5 shows the results from inferential testing of eye-based cues. Both *lids-heavy* and *dozing* reached statistical significance and were more prevalent in trips judged to be possibly impaired than not impaired.

Table 5. Statistical results for eye-based visual cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Lids-heavy	**X^2 = 66.49**	**<0.001**	**14.0%**	**38.8%**	**43.9%**
Dozing	**X^2 = 57.17**	**<0.001**	**0.8%**	**10.4%**	**11.0%**
Blinking, Flitting	.	.	0.0%	0.0%	0.0%

HANDS

Testing for prevalence of *shaking hands* was not completed as no incidents of the visual cue were noted in the selection of files for reduction irrespective of impairment group.

FACIAL

No inferential testing was completed for facial cues due to the lack of behaviors present; for information purposes, the prevalence of each facial cue is presented in Table 6.

Table 6. Statistical results for facial cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Flushed	.	.	0.1%	0.0%	0.0%
Sweating	.	.	0.5%	1.5%	1.2%
Drooling	.	.	0.0%	0.0%	0.0%

HAIR

Testing for *disheveled hair* revealed a significant difference in prevalence between the impairment groups (FET, $p < 0.001$). Impaired drivers had *disheveled hair* in 8.5% of trips compared to 1.5% of trips for those who may be impaired and 0.8% for unimpaired drivers.

CLOTHING

Inferential analyses for clothing-based visual cues were not completed due to insufficient data. For informational purposes, prevalence results are presented in Table 7.

Table 7. Statistical results for clothing cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Shirt Unkempt	.	.	0.2%	0.0%	1.2%
Loosening/Taking Off	.	.	0.0%	0.0%	0.0%

INVOLUNTARY BEHAVIORS

Two identifiers for body-based visual cues, *body tremors or shaking* and *dizziness*, reached statistical significance. Results are presented in Table 8.

Table 8. Statistical results for involuntary behaviors.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Body Tremors or Shaking	**FET**	**0.002**	**0.3%**	**4.5%**	**2.4%**
Dizziness	**FET**	**<0.001**	**1.0%**	**1.5%**	**17.1%**
Nauseous	.	.	0.2%	3.0%	0.0%

RUBBING HEAD OR FACE

No rubbing behaviors were subjected to inferential testing due to the lack of data. Neither *rubbing head* nor *rubbing face* was noted in any of the trip files.

MEMORY

Analyses for memory cues revealed a significant effect for *gets lost* between the impairment groups. Results are presented in Table 9.

Table 9. Statistical results for visual memory cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Gets Lost	**FET**	**0.001**	**1.0%**	**1.5%**	**7.3%**
Repetitive Action	$X^2 = 3.447$	0.179	11.3%	11.9%	18.3%

NERVOUSNESS

Four different nervousness-based cues were tested: *nervous, restless, agitated, and relaxed*. Two of the cues, *restless* and *relaxed*, reached statistical significance (Table 10). Of potential interest is the cue for *nervous*, which was in the opposite direction expected. No occurrences were found for either impaired or potentially impaired drivers, only those who were unimpaired.

Table 10. Statistical results for visual nervousness cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Relaxed	**FET**	**0.001**	**4.1%**	**9.0%**	**13.4%**
Restless	**FET**	**0.003**	**2.9%**	**9.0%**	**8.5%**
Agitated	FET	0.937	3.9%	3.0%	2.4%
Nervous	.	.	2.1%	0.0%	0.0%

MOOD

Inferential testing for mood behavioral cues revealed several statistically significant results (Table 11).

Table 11. Statistical results for visual mood cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Exhilarated	**X^2 = 49.540**	**<0.001**	**3.7%**	**16.4%**	**19.5%**
Talkative	**X^2 = 43.745**	**<0.001**	**14.0%**	**40.3%**	**31.7%**
Rapid Changes in Mood	**FET**	**0.001**	**0.2%**	**3.0%**	**3.7%**
Confused	**FET**	**0.004**	**0.5%**	**4.5%**	**2.4%**
Hostile	.	.	1.8%	1.5%	1.2%
Crying	.	.	0.9%	1.5%	2.4%
Sexually Aggressive	.	.	0.0%	0.0%	2.4%
Extremely Friendly	.	.	0.0%	0.0%	0.0%

COORDINATION

Analyses focusing on cues associated with driver coordination revealed a significant effect between the impairment groups for drivers who displayed *poor posture – cannot sit up* (Table 12).

Table 12. Statistical results for visual coordination cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Posture – Can't Sit Up	**FET**	**<0.001**	**0.9%**	**4.5%**	**13.4%**
Drops/Spills/Knocks Things Over	.	.	0.1%	0.0%	0.0%

NERVOUS SYSTEM

Results from the analyses focusing on the nervous system are provided in Table 13. Statistically reliable differences were noted for *yawning* and *stupor*.

Table 13. Statistical results for visual nervous system cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Yawning	**X^2 = 10.257**	**0.006**	**19.9%**	**35.8%**	**25.6%**
Stupor	**FET**	**<0.001**	**0.3%**	**4.5%**	**17.1%**
Asleep	.	.	0.2%	0.0%	2.4%
Breathing Fast	.	.	0.0%	0.0%	0.0%
Hiccups	.	.	0.0%	1.5%	1.2%
Belching	.	.	0.3%	0.0%	0.0%
Vomiting	.	.	0.0%	1.5%	0.0%
Seizures/Convulsions	.	.	0.0%	0.0%	0.0%

DRINKING

Analyses focused on the visual indication of alcohol consumption revealed reliable results between the three impairment groups. Impaired drivers were seen consuming alcohol in 15.9% of trips compared with potentially impaired drivers (3.0% of trips) and unimpaired (0.1% of trips). Note that for the single trip in which an unimpaired driver was seen imbibing alcohol, the driver did not appear intoxicated.

VEHICLE OPERATION

Results for vehicle operation cues are presented in Table 14 and reveal significant effects for *stopping inappropriately*, *turning abruptly or illegally*, and *swerving*. Of potential interest is the prevalence of *accelerating or decelerating rapidly*, which occurred in the expected direction; however, this behavioral cue along with others was not submitted for inferential testing due to insufficient data.

Table 14. Statistical results for operation cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Stopping Inappropriately	**X^2 = 24.605**	**<0.001**	**1.1%**	**7.5%**	**7.3%**
Turning Abruptly or Illegally	**X^2 = 45.663**	**<0.001**	**1.7%**	**7.5%**	**14.6%**
Swerving	**FET**	**<0.001**	**1.0%**	**1.5%**	**15.9%**
Accelerating or Decelerating Rapidly	.	.	0.8%	1.5%	3.7%
Almost Striking Object/Vehicle	.	.	0.0%	0.0%	0.0%
Slow Speed	.	.	0.0%	0.0%	0.0%
Fast Speed	.	.	0.0%	0.0%	0.0%
Braking Erratically	.	.	0.0%	0.0%	0.0%
Headlights Off	.	.	0.0%	0.0%	0.0%

DRIVING BEHAVIOR

Results from testing for the prevalence of various driving behaviors are presented below (Table 15). Three cues reach statistical significance: *appearing to drive drunkenly, driving, not on roadway*, and *distracted*.

Table 15. Statistical results for driving behavior cues.

Cue	Test	*p*-value	Not Impaired (*n* = 873)	May Be Impaired (*n* = 67)	Impaired (*n* = 82)
Appearing to Drive Drunkenly	**FET**	**<0.001**	**0.0%**	**4.5%**	**25.6%**
Driving, Not on Roadway	**FET**	**<0.001**	**0.2%**	**6.0%**	**4.9%**
Distracted	**X^2 = 40.135**	**<0.001**	**15.2%**	**38.8%**	**35.4%**
Following Too Closely	.	.	0.6%	0.0%	1.2%
Vehicle Defects	.	.	0.0%	0.0%	0.0%
Slow Response Signals	.	.	0.0%	0.0%	0.0%
Improper Signal	.	.	0.0%	0.0%	0.0%

LANE KEEPING

Four cues from lane keeping reached statistical significance: *tires on center line or marker, straddling center line or marker, drifting*, and *turning with wide radius*. A summary of the results is presented below (Table 16).

Table 16. Statistical results for lane keeping cues.

Cue	**Test**	***p*-value**	**Not Impaired (*n* = 873)**	**May Be Impaired (*n* = 67)**	**Impaired (*n* = 82)**
Tires on Center Line or Marker	**X^2 = 59.055**	**<0.001**	12.6%	40.3%	35.4%
Straddling Center Line or Marker	**X^2 = 55.450**	**<0.001**	3.8%	17.9%	20.7%
Drifting	**X^2 = 67.839**	**<0.001**	8.8%	37.3%	28.0%
Turning with Wide Radius	**X^2 = 45.985**	**<0.001**	4.8%	25.4%	12.2%
Driving in Opposing Lane	.	.	0.0%	0.0%	0.0%

CHAPTER 4. DISCUSSION

A behavioral and visual checklist of alcohol intoxication visible in NDS video has the potential to bring significant benefits to naturalistic research. The prevalence of certain visual cues of intoxication was evaluated using the SHRP 2 naturalistic database. Recall that intoxication levels were not determined via BAC or alcohol sensor values but rather by the presence of visual cues, each of which is discussed in greater detail below.

EYES

Two eye-related visual cues were statistically reliable: *lids-heavy* and *dozing*. Both cues were most prevalent with drivers judged to be impaired, with fewer instances in potentially impaired and unimpaired drivers. Results from the current work looking at *lids-heavy* and *dozing* are consistent with previous research in other contexts: in-person interactions with wait staff and observations of intoxicated individuals in social and research scenarios (Landauer & Howat, 1983; McKnight & Marques, 1990; McKnight, 1991). However, of note is that McKnight (1991) and Landauer and Howat (1983) both examined *drowsiness*, as opposed to *dozing*, which was utilized in the current effort. While the two are likely highly correlated, they are not identical. Conversely, a literature review found no evidence that *lids-heavy* correlated significantly with BAC (Rubenzer, 2011). It is conceivable that our findings contradict others due to methodological differences. The ability to pause and rewind video makes the identification of subtle cues much easier in an NDS than in real-time interpersonal interactions.

Recommendations

While visual indicators involving the eyes are potentially a practical cue for use in NDS, a quality (high-resolution image, minimal glare, minimal shadows) view of the driver's face is required. Within the SHRP 2 collection, video was clear enough to determine factors such as *lids-heavy*; however, a data collection with lower-quality video may make identification difficult. A potential conflict relates to the driver's natural level of normal eye closure, or even the presence of glare from driving into the sun. Some individuals may have more naturally relaxed eyelids than others, which may result in false identification of intoxication. If utilized as an intoxication sign, it is recommended that analysts attend to outside light sources and view several of that driver's trips in an attempt to determine an individual's normal level of resting lid closure.

INVOLUNTARY BEHAVIORS

Impaired drivers were far more likely than either potentially impaired drivers or unimpaired drivers to exhibit dizziness. While *dizziness* was found to be a significant cue in the current study, other studies have demonstrated mixed results. While one effort utilized *unsteadiness* (McKnight, 1991), the others relied on *leaning on walls or objects for minor support* (McKnight & Marques, 1990) or *balance maintenance* (McKnight et al., 2002) as an indicator of intoxication. All three cues are arguably similar in presentation to *dizziness*; however, it is possible that minute differences exist between the cues, which may make them better suited to be explored separately. For example, one may lean on walls or objects or be unsteady for reasons other than dizziness. Of note is the argument that while alcohol may produce behaviors which can be interpreted as dizziness, only the drinker is truly aware of the sensation (McKnight, 1988).

However, though McKnight et al. (2002) concluded that *balance maintenance* was significantly correlated with BAC, once the cue was utilized by officers in enforcement-like scenarios, *balance maintenance* no longer proved to be a reliable indicator. Differences in reliability of the cue may be due to drastically different situations. Recall that the current effort utilizes video collected during an NDS, whereas McKnight and colleagues (2002) completed the analyses using interpersonal interactions between police officers and participants. The officers in the study all had field sobriety testing experience, suggesting that balance or dizziness may be more reliably assessed in person or that assessment via NDS video may result in over-assignment of behaviors to dizziness. Additionally, the current effort included *swaying* and *leaning against window* as evidence of *dizziness,* which likely resulted in a higher prevalence.

Recommendations

On the surface, this identifier appears valid as those who have imbibed alcohol may be more likely to exhibit some form of body rigidity loss. Dizziness may prove useful for analyses within NDS video as swaying and leaning against window are both clearly visible from a driver-facing camera. However, direct evidence of being dizzy may be more difficult to attain from video views, especially on straight roadways where the driver's balance is not tested.

NERVOUSNESS

Two visual cues related to nervousness reached statistical significance, *relaxed* and *restless*. The prevalence of a *relaxed* state was highest among impaired and potentially impaired drivers. Additionally, a *restless* state was most prevalent among potentially impaired drivers, with a lower incidence by impaired drivers. In both cases, unimpaired drivers showed the lowest prevalence for the behaviors. Our results for a *relaxed* posture are comparable to those in the literature studying intoxication in social settings (McKnight, et al., 1997; McKnight & Marques, 1990). While the name of the identifier utilized in the social setting studies was *at ease*, the term *relaxed* used in the current work is arguably the same or very similar. Both cited works found *at ease* to be an indicator of intoxication. However, the *at ease* identifier in one analysis occurred with large variability, prohibiting any discrimination between relevant cues (McKnight et al., 1997). Given the difficulty in differentiating between intoxication and general relaxed behavior for an individual portraying a *relaxed* or *at ease* state, it is reasonable that these cues may be assessed differently between studies, resulting in similar or disparate results.

Results from the current effort showed *restless* behaviors to be reliably different among impairment groups. However, when assessing signs of intoxication among drinkers in social situations, *restless* was reported relatively infrequently compared to other indicators such as *red eyes*, *knocks things over*, or *elated* (McKnight & Marques, 1990). This does not mean that restless behaviors are necessarily a poor indicator of intoxication, but that they may not be frequently observed as one. Relatively infrequent observations of relaxed behavior are congruent with the current effort, which showed a prevalence between 8% and 9% of relaxed behavior for intoxicated or potentially intoxicated drivers.

Recommendations

These indicators have the potential to prove useful for intoxication detection via video as body language is readily visible, even in scenarios with lower-resolution video. However, drivers exhibit a relaxed or restless state for many reasons unrelated to alcohol intoxication, including various emotional states or drowsiness, which makes identification utilizing these cues susceptible to false positives. Some individuals may even appear restless as a mechanism to combat drowsiness. While one can imagine that being relaxed or restless may increase crash risk due to longer reaction times, regardless of the source, such cues fail to identify intoxication specifically.

MOOD

Two visual identifiers from the analyses of mood cues revealed significant effects: *exhilarated,* and *talkative*. Evidence of an *exhilarated* mood was most apparent among impaired drivers, with a lower prevalence for potentially impaired and unimpaired drivers. However, *talkative* behaviors were most prevalent among potentially impaired drivers, while impaired drivers exhibited the behaviors less frequently. Other work has produced similar results to the current effort for the identifier *exhilarated* in the ER setting (Cherpitel et al., 2005) and in experimental settings (Sutker et al., 1983). In the ER setting, researchers conducted an interview and assigned an intoxication level to the patient, while a doctor or nurse collected a BAC sample. Euphoria was one of the visual cues used to assign an estimated intoxication level. The total group of cues led to an 85% correct estimation of intoxication. In the experimental setting, increased elation was found for participants during the accumulation phase of intoxication, which dropped once the participants began to process the alcohol (Sutker et al., 1983).

The *talkative* cue has demonstrated conflicting results based on research in social situations (Caudill et al., 1987; Monahan & Lannutti, 2000). Talkative behaviors were prevalent for both intoxicated and potentially intoxicated drivers in this study. Perhaps some of the differences in findings come from the situational differences. Both cited works evaluated participants while interacting with a confederate in a forced social context. However, as this work is naturalistic, the situations are not forced and therefore may result in a different prevalence of talkative behavior. The risks related to various moods and emotional impairment cannot be overstated. Dingus et al. (2016) showed that emotional impairment led to a relative risk of 9.8 times that of model driving, suggesting mood is an important risk factor.

Recommendations

These mood-centric cues are reliably visible in NDS video, even in lower-resolution, making them viable for use in the detection of intoxication. However, each of the cues is also highly correlated with other behaviors or emotional states. Drivers can be exhilarated for any number of reasons, many of which do not include alcohol intoxication. Additionally, talkative drivers may simply be talkative, either naturally so or because of an interesting conversation with a passenger or person on the phone. Researchers who utilize these cues should be wary of falsely associating them with intoxication when assessed on their own.

COORDINATION

One visual cue from the coordination analyses, *posture – cannot sit up*, reached statistical significance. Impaired drivers were more likely than potentially impaired drivers or unimpaired drivers to exhibit the inability to sit up. However, research on the cue, *posture – cannot sit up*, is conflicting (McKnight et al., 1997; McKnight & Marques, 1990). In social situations, *poor posture* was one of the cues used to estimate intoxication; unfortunately, the researchers do not include specific analyses about posture, suggesting it failed to provide meaningful data. No operational definition is provided for *poor posture*, making it impossible to determine if data can be readily compared between the current work and the cited study (McKnight et al., 1997). Conversely, in another social drinking situation, *slouching* was reliably used to determine intoxication (McKnight & Marques, 1990). A postural cue of *slouching* is similar to our cue of *posture – cannot sit up* and provides confirmatory evidence.

One possible explanation for the lack of congruent results may be the different scenarios. The current effort used data collected in a vehicle, while McKnight and colleagues (1997) applied the cue in a social drinking situation. As the participant is already seated in a vehicle, postural changes due to alcohol may be more prevalent compared to social situations where individuals may be standing.

Recommendations

The inability to sit up may prove useful as an intoxication cue in NDS video as gross body movements are readily visible regardless of video quality. However, caution should be applied if one were to view a slouched back posture as a marker for being unable to sit up, as a driver's natural seating position (or one of his/her many natural seating positions) may lead to false associations with intoxication.

NERVOUS SYSTEM

Two visual cues in the nervous system group reached statistical significance: *yawning* and *stupor*. *Yawning* was most prevalent among the potentially impaired and impaired drivers, while *stupor* was most prevalent among impaired drivers, with a lower incidence by potentially impaired drivers. In all cases, unimpaired drivers had the least likelihood of these behaviors. The significance of *yawning* was found to be contrary to previously published works (McKnight & Marques, 1990; Teplin & Lutz, 1985). To develop an observational tool for measuring alcohol intoxication, the authors began with an observation of patients entering the ER. Results showed that yawning was only present in 2% of intoxicated individuals, therefore it was ruled out as a useful identifier for later use in the study (Teplin & Lutz, 1985). Similarly, while developing a tool for observing alcohol intoxication in a social setting, yawning was an initial identifier, but it was discarded due to a lack of reliability in determining intoxication (McKnight & Marques, 1990). A potential explanation for the high prevalence in the current work is the number of trips selected between midnight and 4:00 a.m. The yawning may simply be a product of drowsiness rather than intoxication. If so, the current results may be congruent with previous research.

Stupor was also met with conflicting research (McKnight & Marques, 1990). To the creation of a visual intoxication list in a social drinking scenario, stupor was an intended cue; however, the authors chose not to include it. No indication of dismissal is noted, but if it were a readily viable cue, it would have been included in the checklist given to observers (McKnight & Marques, 1990). Current results revealed a prevalence of 17.1% for *stupor*, which may indicate an incomplete operational definition. *Stupor* was defined as, "Driver has blank glance. Appears 'zoned out.' Not paying attention to surroundings. Steady forward gaze without focusing eyes or scanning driving scene." It is possible that some occurrences of a driver staring blankly ahead were recorded as *stupor* in the absence of alcohol, especially if the driver was drowsy.

Recommendations

While clearly visible in video collected during an NDS, without requiring high-resolution video, these identifiers have the potential to be easily identifiable markers of intoxication. However, both cues suffer from a similar confound to many discussed above: *yawning* and *stupor* are confounded by the time of day selected for many of the trips in the analysis. *Stupor* may prove a more reliable detection cue than *yawning* due to the higher occurrence of *yawning* in unintoxicated drivers.

DRINKING

The visual identifier of *consuming alcohol* reached statistical significance. Impaired drivers exhibited this behavior most frequently, while potentially impaired and unimpaired drivers did so less often. While there is no formal research readily available to indicate that the visible consumption of alcohol can be interpreted as a sign of intoxication, it does serve as a precursor that makes intoxication likely. It would seem prudent to consider any consumption of alcohol as indicative of at least potential intoxication.

Recommendations

This identifier is easily observable in NDS video and has no reasonable confounds when the driver is drinking from an obviously labeled alcohol container. Consuming alcohol is a reliable cue for intoxication and should be utilized as such. However, if alcohol were transferred to another container, NDS video would be unable to determine the presence of alcohol, resulting in a false negative. Given the improbable association of a false positive, this identifier is a benchmark for visible cues, but only if researchers acknowledge the potential of false negatives. Imbibing alcohol is surely seen as evidence for a potentially impaired driver, if not impaired. Note that in this study, 0.1% of unimpaired drivers were found to consume alcohol. This constitutes the rare situation where an individual appeared to be drinking from an alcohol container but did not exhibit any signs of impairment.

VEHICLE OPERATION

Analyses of identifiers related to vehicle operation revealed three cues that reached statistical significance: *stopping inappropriately*, *turning abruptly or illegally*, and *swerving*. Potentially impaired drivers had the highest prevalence of *stopping inappropriately*, while impaired drivers exhibited the behavior less frequently. Impaired drivers were the most frequent group to exhibit *turn abruptly or illegally* and *swerving* compared to the other groups. In all cases, unimpaired drivers had the lowest prevalence. Current results for *stopping inappropriately*, *turning abruptly or illegally*, and *swerving* are congruent with other work in DWI scenarios (Harris, 1980;

Vingilis et al., 1983). The authors noted several driving behaviors and the BAC of individuals arrested for DWI. Each of the above identifiers was noted in the study (minimum prevalence in stops of 31% for BAC > 0.10% and 58% for BAC > 0.05%). In southern Ontario, a police force utilized the checklist created by Harris (1980) to determine pre- and post-intervention arrest rates for DWI. The most frequent identifiers utilized from the checklist included *swerving* and *drifting* (Vingilis et al., 1983). The current results found *drifting* to be an indicator of intoxication. These results are discussed in the subsequent lane-keeping section.

Recommendations

All three of these vehicular operation cues are easily observable from even low-resolution video collected during an NDS. As such, the vehicular operation cues could prove to be a useful indicator for potential intoxication. However, none of cues discussed necessarily *requires* the presence of alcohol and therefore may result in false identifications of alcohol intoxication. For example, stopping inappropriately and turning abruptly or illegally could easily be the result of a driver who is lost, navigating, failing to attend to the roadway as required, or in some circumstances the noted behavior may be a correct evasive maneuver. Swerving may be commonly seen in intoxicated drivers but is also likely present in scenarios with a distracted driver who exhibits poor lane control. As such, the vehicle operation cues are confounded with other common driver behaviors and therefore should not be considered a stand-alone cue.

DRIVER BEHAVIOR

Two visual cues from the driver behavior analyses reached statistical significance, *driving, not on roadway*, and *distracted*. *Driving, not on roadway* was most prevalent among potentially impaired drivers, while impaired drivers and unimpaired drivers exhibited the behavior less frequently. *Distracted* driving was most prevalent among potentially impaired and impaired drivers. Other work has shown consistent findings for *driving, not on roadway* to be a reliable indicator of intoxication in real-world and simulator research (Arnedt et al., 2001; Harris, 1980; Liu & Ho, 2010). Using cues associated with DWI reports, the authors completed a checklist of intoxication cues. *Driving, on other than designated roadway* was utilized in reports both for drivers over 0.10 and those over 0.05 (Harris, 1980). Additionally, in simulated driving environments, participants with a higher BAC performed worse than sober participants on several driving metrics, including the number of off-road events (Arnedt et al., 2001; Liu & Ho, 2010).

Our results showed significant effects for *distracted* behaviors, which is supported by research based on FARS data (Wilson et al., 2013) and using a driving simulator (Rakauskas et al., 2005). Using FARS data, the authors showed that drivers who were simultaneously distracted *and* intoxicated were involved in a greater than 63% rise in fatal crashes from 2005 to 2009, suggesting that distraction may be more likely for intoxicated drivers, that intoxicated drivers are less able to multi-task, or that simply the combination of both is more dangerous than either alone (Wilson et al., 2013). Additionally, in the simulator research, the authors concluded that intoxicated individuals at the 0.08 level were less attentive to external stimuli and showed a weaker response to novel sounds when engaged in a secondary task, suggesting that intoxication affects divided attention as well as increases distraction with secondary tasks (Rakauskas et al., 2005).

Recommendations

Operation of a vehicle off the roadway would be a valid visual cue to evaluate the possibility of an intoxicated driver and is easily seen in video collected during an NDS study. However, this identifier should only be considered in the absence of any outside force requiring the maneuver. False positives could arise if the driver intends to leave the roadway, either intentionally due to an evasive maneuver or simply as an exhibition of horse play. Distraction can be a useful cue as it is readily visible in video, though video of the driver's face and hands would be helpful, if not required. Use of distraction as a cue for intoxication is confounded. Drivers who appear to be distracted can be distracted for any number of reasons including a phone, a nearby sight, or conversation.

LANE KEEPING

Four cues associated with lane keeping reached statistical significance: *tires on center line or marker, straddling center line or marker, drifting,* and *turning with wide radius*. Potentially impaired drivers were the most likely (followed by impaired drivers) to exhibit the behaviors of *tires on center line, drifting,* and *turning with wide radius.* However, impaired drivers had the highest prevalence (followed by potentially impaired drivers) of *straddling center line or marker*. For all cues, unimpaired drivers had the lowest prevalence. The current results for lane keeping cues (*tires on center line or marker, straddling center line or marker, drifting,* and *turning with wide radius*) are also consistent with previous research among DWI reports and simulator research (Harris, 1980; Huemer & Vollrath, 2010; Weafer et al., 2008). In creating a checklist of indicators used to initiate a DWI, the authors noted several applicable cues. Each of the above cues was noted as a potentially important indicator for intoxication and present in at least 46% of cases with a BAC over 0.10 or 67% of cases with a BAC over 0.05 (Harris, 1980). In simulated environments, sober participants performed better during lane maintenance tasks than intoxicated participants (Huemer & Vollrath, 2010; Weafer et al., 2008). In another effort, several aspects of lane control, including weaving, drifting, swerving, and turning with a wide radius, were used to develop an app to detect intoxicated driving (Dai et al., 2010).

Recommendations

Lateral control near the center line of the roadway could prove to be a valuable cue. It is clearly visible in NDS video but unfortunately is also confounded with drowsiness and distraction. Poor vehicular control near the center markers is likely present in situations with a drowsy and/or distracted driver. As a sole cue for intoxication, it may be prone to false positives, especially during more common times of the day for drowsiness such as late at night or early in the morning.

While drifting within a lane may prove a useful cue given that it is easily visible from NDS video, it also is confounded with drowsiness and distraction and therefore may result in false positives. If one wants to include drifting as a potential identifier, it is suggested that distraction-related maneuvers and time of day be considered as well as the cause of drifting. Note that a driver may choose to move within the lane for many reasons, including avoidance of potholes, manholes, debris, or to improve visibility around other traffic. Thus, it is not always indicative of impairment or increased risk.

A wide turning radius may work well as an identifier through NDS video collection, but, again, it may be subject to false positives as drowsy and distracted drivers may less accurately judge the space needed to complete a turn. Poor visibility of the curb or edges of the roadway (especially during times of less ambient light) may also lead a driver to drop a tire off the roadway or strike the curb. Turning with a wide radius may provide insight into possible intoxication, but due to confounds ,it likely cannot function as a stand-alone cue.

CHAPTER 5. LIMITATIONS

CIRCULAR LOGIC

A primary limitation of the current work is the problem of circular logic. Analysts coded for signs of impairment based on the presence of visual cues. Unfortunately, these were also the same visual cues used to determine the presence of intoxication. Recall that reductionists were instructed not to utilize the alcohol sensor output. Given this limitation, a very conservative interpretation of the results is warranted. Compounding this problem is that the same group of analysts coded the visual cues in both instances.

CONFOUNDS AND INTERCONNECTIVITY

The alcohol sensor used in the SHRP 2 collection has been shown to react to inert substances such as windshield washer fluid, hand sanitizer, perfume, cigarette smoke, and even fast food (Smith et al., 2015). While this limitation highlights the need for some form of evidentiary (e.g., video-based) evaluation rather than relying on alcohol sensor readings alone, neither should the identifiers discussed above be considered definitive. Each of the cues discussed prior can be attributed to alcohol intoxication, but also can be explained in relation to other phenomena.

Confounding factors are discussed below as they relate to the identification of intoxication via the visual identifiers studied. Because of the difficulty of teasing apart which events are truly due to the presence of alcohol intoxication and which may be the result of other risky behaviors, the results from this work are strongly caveated. It is also worth considering that the behaviors noted may be caused by or exacerbated by alcohol intoxication. For instance, a driver may express an exhilarated mood either due to intoxication directly, as an indirect result of intoxication, or even for an unrelated reason. Similarly, both a sober and an intoxicated behavior may engage in secondary tasks and be distracted, but the appearance and/or impact of that distraction may change with the level of intoxication.

Drowsiness

This effort suffers from a major confound. Many trips selected focused on those where drivers are more likely to be intoxicated. Due to the time of day (midnight to 4:00 a.m.), drivers at this time are also more likely to be drowsy. Nearly all identifiers evaluated are also likely to be present in a drowsy individual. As such, there is no reliable way to tease apart the behavior and determine if it is the result of intoxication or drowsiness.

Emotional State

Several of the emotional identifiers that reached statistical significance (*relaxed*, *restless*, *talkative*, and *exhilarated)* suffer from poor validity in intoxication detection. For instance, a driver exhibiting a *relaxed* behavioral state could be doing so for any number of reasons including drowsiness, recently completed exercise, or even completion of a major work task. None of these common explanations require alcohol intoxication to be present. A similar pattern exists for the *restless*, *talkative*, and *exhilarated* emotional states. The confounds associated with emotional states and the difficulty associated with separating out those caused by intoxication renders these identifiers unreliable on their own.

Distraction

Vehicle operation cues that reached significance (*stopping inappropriately, turning abruptly or illegally, driving, not on roadway, tires on center line or marker, straddling center line or marker, drifting,* and *turning with a wide radius*) also suffer from confounds, which makes them difficult to associate with alcohol intoxication. Driver distraction is quite common and has been shown to be prevalent in nearly 52% of baseline driving events (Dingus et al., 2016). Given the high prevalence of distraction and how it can affect driver performance, it would be unfair not to account for the presence of secondary tasks. Unfortunately, during the initial reduction process, secondary task engagement was not recorded. As such, in the current dataset we are unable to determine which vehicular control identifiers were related to intoxication rather than distraction.

REPRESENTATIVENESS

The set of sampled driving trips was intended to maximize the number of events likely to contain intoxicated driving and not to be a representative sample of all driving. It is conceivable that results would have varied had the sampling method attempted to sample from *all* trips randomly. Recall that this effort used alcohol sensor values to select the first 635 trips and then sampled randomly for the remaining 387 regardless of day or time leaving the sample biased towards alcohol-prone trips. It is also plausible that with trips collected during a time when the driver is less likely to be drowsy, more robust results may be achieved.

INDIVIDUAL DIFFERENCES

Additionally, many of the emotional or nervous system cues may present themselves in a variety of ways due to individual differences. One individual becomes talkative when intoxicated, while others become relaxed or restless. Additionally, research has shown that those with high levels of alcohol tolerance may not exhibit the same physical manifestations of intoxication as typical drinkers (Perper et al., 1986; Roberts & Dollard, 2010; Sullivan et al., 1987). Drivers who are frequently intoxicated may not show the same or any visible signs of a high BAC level, at which point visual indicators are rendered ineffective. Given the individual differences in both emotional expression and alcohol tolerance, it is likely that a much larger sample would be required to ensure enough data for each potential presentation. In related work on assessing observer-rated drowsiness, the authors have shown that it is exhibited differently for each person, and that individual differences are too important to ignore (Wiegand et al., 2009).

FUTURE WORK

Future work where no reliable ground truth is available for comparison can benefit from having two distinct groups of analysts—one to assign intoxication level and the other to code for behaviors. Doing so may have provided some protection against circularity. Additionally, subsequent efforts should focus on utilizing an accurate alcohol intoxication measurement, perhaps a breathalyzer, while collecting driving data in a simulator, which would provide a ground truth for comparisons and allow for assessment of visual signs of intoxication. Finally, current analyses looked at each behavioral or visual cue independently. Future work can employ more sophisticated statistical techniques to incorporate the most salient of these cues together in a single model of impaired driving.

CHAPTER 6. CONCLUSION

The search for a set of visual cues that can reliably detect the presence of alcohol intoxication is not met without difficulty. Given that so many of the visual cues evaluated can also be present in distracted or drowsy drivers and vary greatly by individual, one cannot rely solely on any of the cues in isolation to detect alcohol intoxication. Even in aggregate, the cues taken together would benefit considerably from additional testing against an objective valuation of intoxication. However, these cues can prove useful in research to eliminate false positives when relying on an in-cabin alcohol detector such as those in the SHRP 2 NDS. As noted previously, the alcohol sensor used has been shown to react to several non-intoxicating substances, such as fast food, windshield washer fluid, perfume, and hand sanitizer. After using alcohol sensor values to identify potential intoxication-based events, researchers could then capitalize on the present effort to eliminate events where the sensor detected alcohol incorrectly. For instance, if an event where alcohol sensor values suggest the presence of alcohol, but none of the visual indicators above are present, the event can likely be set aside as a false positive. Conversely, alcohol sensor values suggesting the presence of alcohol along with visual indicators from this work would help to verify the correct interpretation of intoxication. Employing more sophisticated multivariate logistic regression modeling techniques may help to overcome some of these limitations.

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