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Streamlining Drowsiness Assessment: An In-Depth Review of ORD and PERCLOS Methods

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EXECUTIVE SUMMARY

Every year, drowsy and fatigued driving contributes to thousands of crashes and their resulting injuries and fatalities (National Center for Statistics and Analysis, 2017). From 2011 to 2015, an estimated 396,000 crashes in the US involved drowsy driving, resulting in 3,662 fatalities and 160,000 injuries (National Center for Statistics and Analysis, 2017). Further, the Large Truck Crash Causation Study showed drowsy driving in 13% of truck-involved crashes sampled from the period April 2001 to December 2003 (Federal Motor Carrier Safety Administration, 2005). However, these estimates likely underestimate how often drowsiness contributes to crashes.

Naturalistic driving data allows researchers an opportunity to better understand drowsy driving, through review of driver-facing video capturing the driver's behavior and eyes. Naturalistic driving data collected from commercial truck and motorcoach drivers in the Onboard Monitoring System Field Operational Test (OBMS FOT) was recently reduced in the Naturalistic Driving Data study (Hammond et al., 2021). For a subset of events, reduction of this data included two drowsiness measures that have been successfully used in naturalistic driving data: Observer Rating of Drowsiness (ORD) (Wiegand, McClafferty, McDonald, & Hanowski, 2009) and manual percentage of eye closure (PERCLOS) (Wierwille & Ellsworth, 1994).

The current study explored how different drowsiness measures impact fatigue determination for an event and study estimates of fatigue prevalence, risk, and secondary task association for truck and motorcoach drivers. Analyses investigated PERCLOS scores using 1 minute of data (PERCLOS 1) versus 3 minutes of data (PERCLOS 3). The study found the sample size of events with PERCLOS data increased by 8.94% when PERCLOS 1 criteria were used. Overall, matching fatigue determination (whether fatigue was observed) in PERCLOS 3 and PERCLOS 1 scores was found for between 95.89% and 99.48% of truck and motorcoach baselines (BLs) and safety-critical events (SCEs). The risk of SCE involvement when driving while fatigued was consistent for truck drivers when using PERCLOS 1 or PERCLOS 3 to determine fatigue. However, for motorcoach drivers, the risk of SCE involvement when driving while fatigued depended on the PERCLOS measure used.

The study also aimed to determine how to potentially lessen the effort of fatigue data reduction in future studies and obtain the most valuable dataset at the lowest cost to time and budget. An analysis of ORD scores for events meeting the manual PERCLOS fatigue threshold was conducted to identify if an ORD score threshold could potentially be used to screen events or video files registering higher levels of fatigue for additional PERCLOS reduction. The study found that the single fatigue reduction approach with the lowest time and cost budget was PERCLOS 1 for all events. However, a targeted fatigue reduction approach that includes ORD for all events and targeted PERCLOS 3 or PERCLOS 1 reduction for events that meet or exceed an ORD threshold can reduce the cost of fatigue reduction while maintaining the advantage of ORD reduction.

The current study provides important insight into the impact the drowsiness assessment method can have on the range of drowsiness captured, the number of events to assess, and the time and monetary budget for fatigue reduction. As researchers evaluate the best drowsiness measurement method for a particular study, it will be key to consider these points in context with the research questions and the purpose for which they are assessing drowsiness.

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LIST OF ABBREVIATIONS AND SYMBOLS

BL	baseline
CI	confidence interval
CMV	commercial motor vehicle
DAS	data acquisition system
FMCSA	Federal Motor Carrier Safety Administration
LCL	lower confidence limit
NHTSA	National Highway Traffic Safety Administration
OBMS FOT	On-Board Monitoring System Field Operational Test
OR	odds ratio
ORD	observer rating of drowsiness
SCE	safety-critical event
SHRP 2	Strategic Highway Research Program 2
UCL	upper confidence limit
USDOT	United States Department of Transportation
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

Every year, thousands of crashes and their associated injuries are the result of drowsy and fatigued driving (National Center for Statistics and Analysis, 2017). From 2011 to 2015, an estimated 396,000 crashes involved drowsy driving, resulting in 3,662 fatalities and 160,000 injuries (National Center for Statistics and Analysis, 2017). A recent study of light vehicle drivers from the Second Strategic Highway Research Program 2 (SHRP 2) data collection showed drowsy driving in 9.5% of crashes (Owens et al., 2018). The Large Truck Crash Causation Study showed drowsy driving in 13% of truck-involved crashes sampled from the period April 2001 to December 2003 (Federal Motor Carrier Safety Administration, 2005). The same study identified fatigue as a "Top 20" factor in large truck crashes (FMCSA, 2005).

Driver drowsiness and driver fatigue are both considered types of driver impairment, with similar signs and symptoms but not the exact same meaning (National Highway Traffic Safety Administration, n.d.). Fatigue has been defined as reduced alertness (National Surface Transportation Safety Center for Excellence, 2017) and affected judgement (National Institute for Occupational Safety and Health, 2023) as a "result of physical or mental exertion that impairs performance" (Federal Motor Carrier Safety Administration, 2015). Drowsiness is associated with sleepiness and can also impair performance and reaction time (Virginia Tech Transportation Institute, 2017; Federal Motor Carrier Safety Administration, 2015). The terms "drowsiness" and "fatigue" will be used interchangeably in this report to describe impaired driving where the driver is exhibiting visible behavioral signs associated with tiredness and reduced alertness.

Many estimates of drowsy driving prevalence are calculated using data from police accident reports, which rely on verbal accounts of driver behavior and other driving and environmental indicators. This may lead to underestimating the prevalence of drowsiness in crashes. Naturalistic driving data, collected from video cameras and sensors installed on vehicles used by participants on public roadways during routine driving, provides an opportunity to better understand drowsy driving. Researchers can thoroughly review video capturing drowsy driving as it occurs in the real world. During this review, researchers can note driver behaviors, environmental and roadway conditions, and measure driving time durations. Two drowsiness measures have been successfully used in naturalistic driving data: Observer Rating of Drowsiness (ORD) and manual percentage of eye closure (PERCLOS). ORD measures drowsy driving with a subjective assessment of the driver, "based on his/her physical appearance, behaviors, and mannerisms" (Wiegand, McClafferty, McDonald, & Hanowski, 2009). ORD is rated on a scale of 0 ("not drowsy") to 100 ("extremely drowsy"), where the final ORD score for a single event or baseline epoch (i.e., normal driving) is obtained by calculating the average score from three trained reductionists. Manual PERCLOS is the percentage of time when the driver's eyes are "80 to 100 percent closed" (Wierwille & Ellsworth, 1994) and is coded by a single reductionist reviewing each sync for 1 minute (PERCLOS 1) up to 3 minutes (PERCLOS 3) leading up to an event or baseline epoch. In follow-up analyses, ORD and PERCLOS scores can be used to make a "fatigue determination" about a moment of driving: when the ORD score or PERCLOS score reaches or exceeds a specified value, the driver is said to be fatigued (and conversely, if the scores are under the specified value the driver is said to not be fatigued).

The Onboard Monitoring System Field Operational Test (OBMS FOT) study collected naturalistic driving data from commercial drivers of trucks and motorcoach buses (Boyle, Guo, Hammond, Hanowski, & Soccolich, 2016). The naturalistic driving data was reduced in a follow-on study (Hammond et al., 2021) and included both ORD and PERCLOS 3 reduction for a subset of events. Performing multiple drowsiness measures on the same set of safety-critical events (SCEs) and baselines (BLs) found that drowsiness measured using ORD was observed more frequently than when using PERCLOS 3. However, the correlation between ORD and PERCLOS 3 drowsiness ratings showed a weak relationship between the two measures. The reduction of both ORD and PERCLOS 3 in Hammond et al. (2021) provided a unique opportunity to compare the drowsiness measures for strengths, weaknesses, similarities, and differences.

Both ORD and manual PERCLOS are time-intensive reduction efforts, as multiple reductionists are needed to complete ORD, and manual PERCLOS is conducting sync-by-sync (1 sync = $1/10^{th}$ of a second). The current study aims to examine the relationship across the ORD, PERCLOS 1, and PERCLOS 3 drowsiness measures to suggest how to potentially lessen the effort of reductionists in future studies and obtain the most valuable dataset at the lowest cost to time and budget. Manual PERCLOS is conducted by coding whether the driver's eyes are open or closed for each sync of the data across a period of time (this is described in more detail in Chapter 2). The current study used the PERCLOS 3 values calculated in Hammond et al. (2021) then calculated PERCLOS 1 values from the raw coded data that was used to originally calculate PERCLOS 3 (i.e., PERCLOS 1 is a subset of PERCLOS 3). The current study then compared the PERCLOS 3 scores to the newly calculated PERCLOS 1 scores for all OBMS FOT events to assess if there is a significant difference in scores.

Furthermore, analyses conducted in Hammond et al. (2021) using PERCLOS 3 to assess fatigue prevalence, risk, and secondary task association were re-run with PERCLOS 1 ratings (i.e., using 1 minute of data just prior to an SCE or BL versus 3 minutes of data just prior to the same SCE or BL) to evaluate if and how findings changed. The results of this analysis are described in Chapter 3. Additionally, the current study compared ORD scores to manual PERCLOS scores for the same SCEs or BLs to evaluate the difference between these two measures. Drowsiness reduction using ORD can be cheaper than manual PERCLOS 3, which may be helpful in reducing drowsiness reduction budgets in future studies.

CHAPTER 2. METHODS

The current study utilized data originally collected during the OBMS FOT study (Boyle, Guo, Hammond, Hanowski, & Soccolich, 2016) and further reduced during the Naturalistic Driving Study (Hammond et al., 2021). The reports for each of these previously completed studies contain detailed information regarding participating carriers, data collection tools, and analysis methodology. A brief description of the data analyzed in the current study is included here for reference.

The naturalistic driving data was collected from seven truck or motorcoach fleets. The study participants included 172 truck drivers and 73 motorcoach drivers. Participating drivers operated a fleet truck or motorcoach bus, installed with a data acquisition system that included five video cameras and many sensors, which collected video and kinematic data continuously when the vehicle was on and in motion. The naturalistic driving data was processed using algorithms that identify driving epochs that meet or exceed sensor trigger values associated with SCEs. These driving epochs were reviewed by trained reductionists, who assessed the validity of the SCE. In addition to SCEs, baseline driving epochs, or BLs, (i.e., normal driving or non-events), were also identified. BLs and SCEs undergo additional review based on study needs. For the Hammond et al. (2021) study, the additional review included reduction for environmental conditions, driver behaviors, secondary task engagement, and driver drowsiness, and more.

The current study assessed driver drowsiness data and secondary task engagement data from SCEs and BLs, from both truck and motorcoach drivers. Although drowsiness and fatigue are related, they are not exactly the same. In the current study, the terms will be used interchangeably to describe driving while demonstrating visible behaviors associated with tiredness and sleepiness.

2.1 ORD APPROACH

ORD is a subjective measurement of drowsiness based on observed behaviors and mannerisms associated with drowsy driving. The ORD approach is described in detail in Wiegand et al. (2009) and Hammond et al. (2021). Included below are examples of these behaviors and mannerisms.

- ***Eyes/eyebrows* –** rubbing or scratching, blank or fixed stare, squinting, excessive or hard blinking, slow closure, glassy or glazed eyes, raising eyes or opening eyes wide
- ***Body*** – slumping, slouching, leaning, sighing, stretching, changing body position as sign of restlessness
- ***Mouth* –** yawning, biting or licking lips, tongue motion
- ***Face* –** rubbing or holding face, contorting face, slack muscle tone
- ***Neck/head* –** scratching or straightening hair, rubbing or holding neck, unsupported head leaning back or to the side, changing head position, head nodding or drooping

ORD relies on trained researchers to assess the average observed drowsiness during the period immediately prior to the SCE or BL start. Drowsiness is rated on a scale from 0 to 100 and includes five categories: not drowsy (0 to 12.49), slightly drowsy (12.50 to 37.49), moderately drowsy (37.50 to 62.49), very drowsy (62.50 to 87.49), and extremely drowsy (87.50 to 100). For each SCE or BL, a trained reductionist watches the sampled video and rates drowsiness on a sliding scale (Figure 1). ORD ratings are traditionally based on 60 seconds of video prior to the start of the SCE or BL. For the OBMS FOT data used in the current study, if an SCE or BL did not have a full 60 seconds of video available for observation, it was still assessed for ORD if there was at least 30 seconds of video available. ORD ratings represent the average level of drowsiness observed during the full video sample.

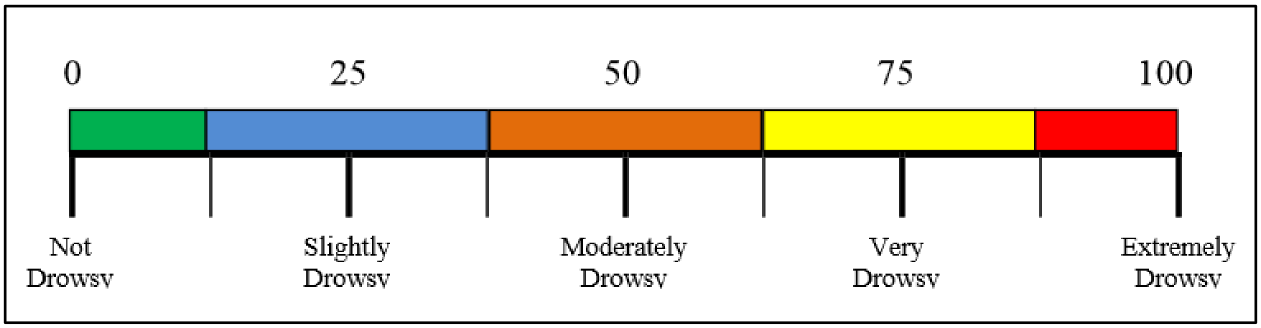

Figure 1. Diagram. ORD rating sliding scale.

ORD scoring protocol (Figure 2) requires each SCE/BL to be rated by three trained reductionists. The reductionists watch the video separately and submit an individual ORD rating. If all three scores fall within the approved quality control range (within 30 points of each other), the final ORD score is calculated as the average of the three ORD ratings. Any SCEs/BLs with scores that did not fall within the approved quality control range were re-reviewed until ORD scoring criteria were met.

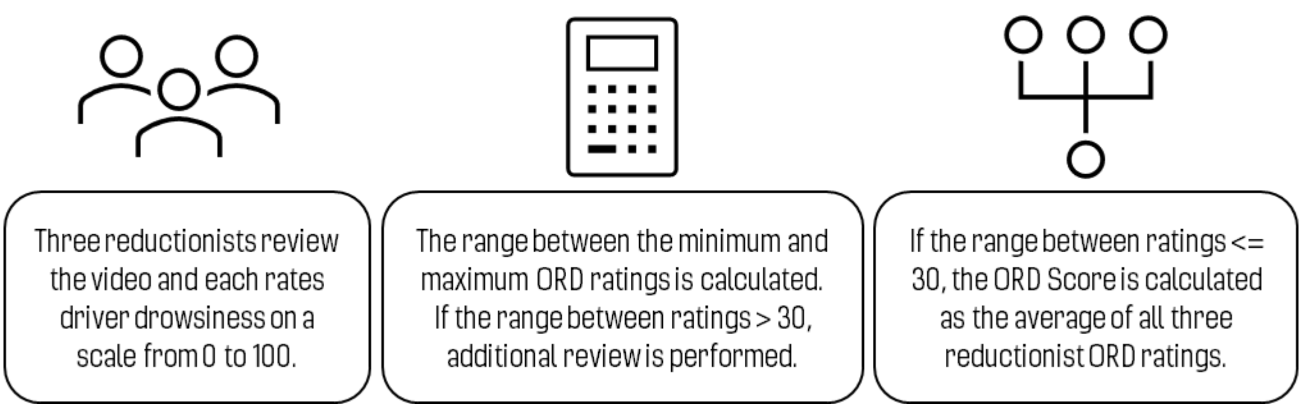

Figure 2. Diagram. Protocol for calculating ORD score.

For the OBMS FOT study, SCEs and BLs were marked as fatigued or not fatigued based on the ORD score. This is the ORD "fatigue determination" of the SCE or BL. An SCE or BL was considered “fatigued” if the ORD score was 62.50 and up (very and extremely drowsy categories). SCEs or BLs with scores under 62.50 were considered “not fatigued.”

2.2 MANUAL PERCLOS APPROACH

Manual PERCLOS is a drowsiness assessment based on eye closure during the time period prior to SCE or BL start. Manual PERCLOS is a calculation of the proportion of time the driver’s eyes were closed at least 80% of the way. Figure 3 shows the process for calculating a manual PERCLOS score. A trained reductionist watches 3 minutes of video just prior to the start of the SCE or BL and marks each sync as “eyes closed” 80%–100% of the way or “eyes open.” Because manual PERCLOS is assessing driver drowsiness, eye closures due to blinking, considered 1 to 2 syncs in duration, are not included in the calculations. For the entire sample, the total time with “eyes closed” is divided by the total sampled time to calculate the PERCLOS score. Because manual PERCLOS is scored as a proportion, a PERCLOS score ranges between 0 (eyes never closed at least 80% of the way) and 100 (eyes always closed at least 80% of the way).

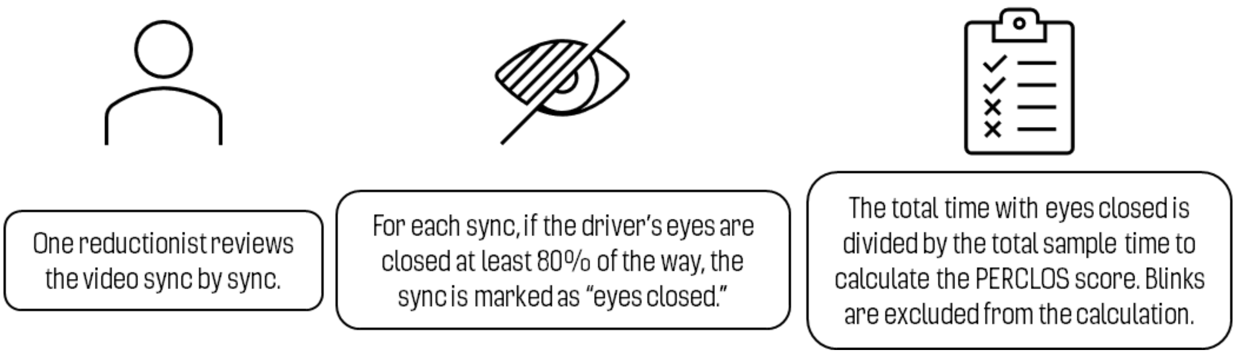

Figure 3. Diagram. Process for calculating manual PERCLOS scores.

To calculate PERCLOS 3 for an SCE or BL, 3 minutes of video data prior to the start of the SCE or BL are needed. At times, the SCE or BL occurs at the beginning of the video file and therefore the full 3 minutes may not be available. In these instances, manual PERCLOS is typically conducted on the available video as long as at least 1 minute of video is available. Since the goal of the current study is to compare the values of PERCLOS 3 to PERCLOS 1, PERCLOS 1 was also calculated for events that have PERCLOS 3 data. That is, the PERCLOS 1 values used in this report were calculated from a subset of the original PERCLOS 3 coded data.

2.3 ANALYSIS APPROACH

As noted above, PERCLOS 1 was calculated for all events with existing PERCLOS 3 scores. The PERCLOS score calculation can be used to determine fatigue in a binary approach; that is, if the PERCLOS score calculation meets or exceeds a specified threshold. This is the PERCLOS “fatigue determination” of the SCE or BL. While this threshold has been studied extensively in the past and can range in value (Hanowski et al., 2008a; Hanowski et al., 2008b; Owens et al., 2018; Wierwille et al., 1994a; Wierwille et al., 1994b; Wierwille et al., 1999, pp. 31-52), the Hammond et al. (2021) study used a fatigue threshold of 12% to mark SCEs and BLs as fatigued or not fatigued. If the PERCLOS score was greater than 12% (that is, the driver’s eyes were closed at least 80% of the way for more than 12% of the 3-minute video sample), the SCE or BL was considered "fatigued." If the PERCLOS score was 12% or lower, the SCE or BL was considered "not fatigued." Events were coded for fatigue first by comparing their PERCLOS 3 score calculation to the threshold. This was repeated using the PERCLOS 1 score calculation.

The first analysis compared PERCLOS 1 scores to PERCLOS 3 scores, with the scores treated as continuous values. A linear mixed model regression approach was used to model the difference in PERCLOS 1 and PERCLOS 3 scores and to assess the correlation between PERCLOS 1 and PERCLOS 3 scores for a single event. The model predicted the PERCLOS 1 score by the PERCLOS 3 score. A unique model was built for each study vehicle group. The model included a random effects term for participant to control for correlation in data per participant. To determine if events met the fatigue threshold under both PERCLOS 1 and PERCLOS 3, a follow-up analysis compared the PERCLOS 1 binary fatigue rating and PERCLOS 3 binary fatigue rating. The analysis presents the cross-tabulation of fatigue ratings by PERCLOS calculation type, event type, and vehicle type, with event counts and percent calculations.

The Hammond et al. (2021) study assessed the relationships between SCE involvement, driver distraction, and drowsy driving, using PERCLOS 3 to measure fatigue. Rates of fatigue were compared in SCEs and BLs, in events with some sort of secondary task involvement compared to events without any secondary task involvement, and in specific secondary tasks compared to events without the specific secondary task. In the current study, previous study findings were reassessed using PERCLOS 1 in place of PERCLOS 3. The same analyses were performed, now with the PERCLOS 1 binary fatigue rating in place of the PERCLOS 3 binary fatigue rating. The analysis used generalized linear mixed-effect models and resulting odds ratios (ORs) and 95% confidence intervals (CIs) to estimate the risk of SCE involvement during fatigued driving. The analysis used the same approach to assess the risk of fatigue during distracted and non-distracted driving. Additional details explaining the approach are included in Hammond et al. (2021). The OR and 95% CI for SCE involvement when fatigued was calculated using PERCLOS 3 and PERCLOS 1.

The final analysis investigated how a multifaceted drowsiness reduction approach could be used to maximize drowsiness data collection and reduce drowsiness reduction costs. The hypothesis was that ORD, which is a more subjective but lower cost drowsiness reduction approach, could be used to identify events likely to have fatigue, and this subset of events could then undergo PERCLOS reduction to obtain an objective drowsiness assessment at a higher cost. To understand how ORD could be used to screen events for PERCLOS reduction, ORD ratings for PERCLOS 3 and 1 fatigued events and non-fatigued events were compared. The ORD rating threshold that the PERCLOS fatigued events met or exceeded was identified. Estimates of reduction time and cost were calculated and compared for several drowsiness reduction approaches:

- One drowsiness reduction approach performed on all events (ORD only, PERCLOS 3 only, PERCLOS 1 only);
- Two drowsiness reduction approaches performed on all events, as done in Hammond et al. (2021) (ORD and PERCLOS 3, ORD and PERCLOS 1);

- ORD performed on all events and targeted PERCLOS reduction on events meeting or exceeding the ORD rating threshold (ORD and targeted PERCLOS 3, ORD and targeted PERCLOS 1).

CHAPTER 3. RESULTS

3.1 COMPARING PERCLOS 1 SCORES TO PERCLOS 3 SCORES

In the Hammond et al. (2020) study, PERCLOS 3 was calculated for 6,981 BLs and SCEs. The term "events" as used in this chapter indicates BLs and SCEs considered together in one sample. The study data had 624 events that did not meet PERCLOS 3 criteria and did meet PERCLOS 1 criteria; these additional PERCLOS 1 events increase the PERCLOS sample size by 8.94% events. Table 1 presents the breakdown of events with PERCLOS 1 and PERCLOS 3 score calculations by study vehicle. Motorcoach events included 3,358 with PERCLOS 3 score calculations and 287 additional events with PERCLOS 1 score calculations. Truck events included 3,623 with PERCLOS 3 score calculations and 337 additional events with PERCLOS 1 score calculations.

Table 1. Event count for PERCLOS 1 and PERCLOS 3 score calculations by study vehicle.

PERCLOS Calculation Type	Motorcoach Events	Truck Events	Total Events
Events with PERCLOS 3 and PERCLOS 1 score calculations	3,358	3,623	6,981
Additional events with only PERCLOS 1 score calculations	287	337	624

3.1.1 Comparison of PERCLOS Score Calculations as Continuous Values

The PERCLOS score for a single BL or SCE is the proportion of time the driver's eyes were at least 80% closed. The calculation can fall within the range of 0 to 100. The following analysis compares the PERCLOS 3 and PERCLOS 1 score calculations (as continuous values) for events with both PERCLOS calculations, by vehicle type.

Figure 4 is a scatterplot of the PERCLOS 1 and PERCLOS 3 score for each motorcoach event (BL and SCE). The plot shows an overall strong positive relationship between the two scores. The linear mixed model solutions for fixed effects are shown in Table 2. The model estimates that on average, a motorcoach event's PERCLOS 1 score is approximately 0.9522 times the event's PERCLOS 3 score, plus 0.0004 (model intercept value). The PERCLOS 3 score is a significant predictor of the PERCLOS 1 score ($p < 0.0001$). Additional models by event type showed similar outcomes: PERCLOS 3 score was a significant predictor of PERCLOS 1 score ($p < 0.0001$, for both the BL and SCE models). The BL model coefficient estimate for the PERCLOS 3 score fixed effect was 0.9991, showing a near 1:1 relationship between PERCLOS 3 score and PERCLOS 1 score (model intercept value = −0.00005). The SCE model coefficient estimate for the PERCLOS 3 score fixed effect was not quite as strong at 0.9011, with an intercept value of 0.0007. Tables with BL and SCE model output are included in the Appendix.

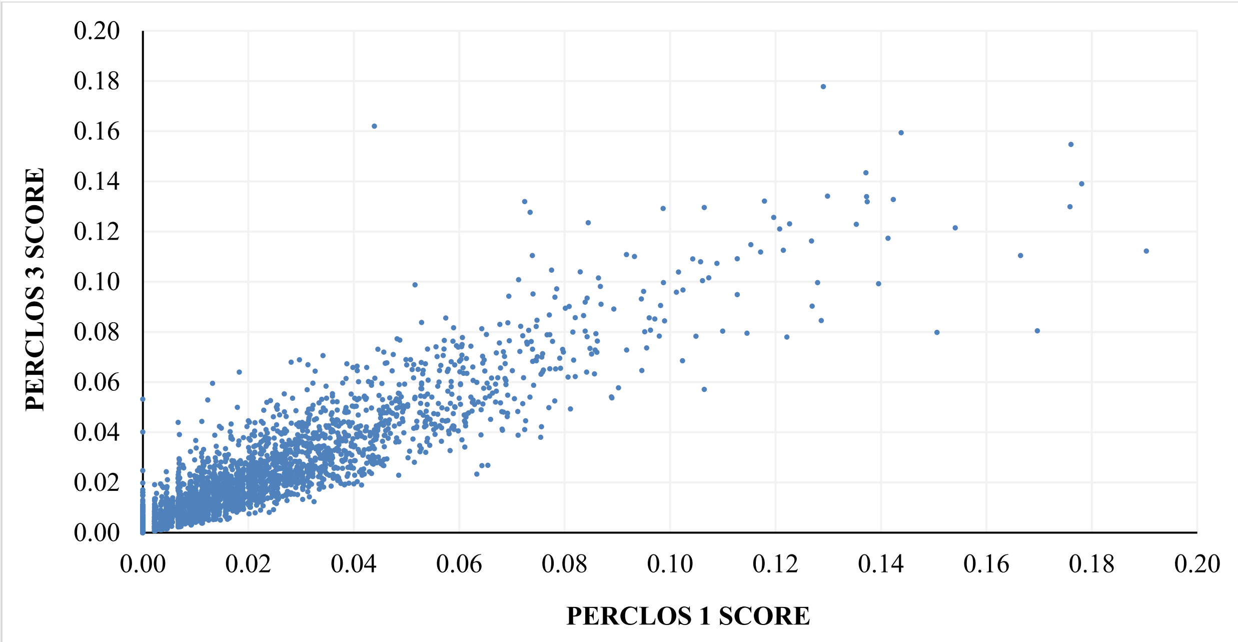

Figure 4. Graph. PERCLOS 1 score versus PERCLOS 3 score for motorcoach BLs and SCEs.

Table 2. Motorcoach linear mixed model solutions for fixed effects.

Effect	Estimate	Standard Error	*df*	*t*-value	*p*-value
Intercept	0.0004	0.0002	140.50	1.61	0.1102
PERCLOS 3 Score	0.9522	0.0078	726.10	121.77	<.0001

Figure 5 is a scatterplot of the PERCLOS 1 and PERCLOS 3 score for each truck event (BL and SCE), and the plot shows an overall strong positive relationship between the two PERCLOS calculations. The linear mixed model solutions for fixed effects are shown in Table 3. From the model, on average, an event's PERCLOS 1 score is slightly higher than the event's PERCLOS 3 score. The model predicts an event's PERCLOS 1 score to be approximately 1.0170 times the PERCLOS 3 score, minus 0.0018 (intercept value). The PERCLOS 3 score is a significant predictor of the PERCLOS 1 score ($p < 0.0001$). Additional models by event type found PERCLOS 3 score to be a significant predictor of PERCLOS 1 score ($p < 0.0001$, for both the BL and SCE models). For BLs, on average the PERCLOS 1 score is estimated to be slightly lower than the PERCLOS 3 score (coefficient estimate = 0.9669, intercept = 0.0002). The SCE model found the PERCLOS 1 score to be slightly higher on average than the PERCLOS 3 (coefficient estimate = 1.0323 score, intercept = −00024). Tables with BL and SCE model output are included in the Appendix.

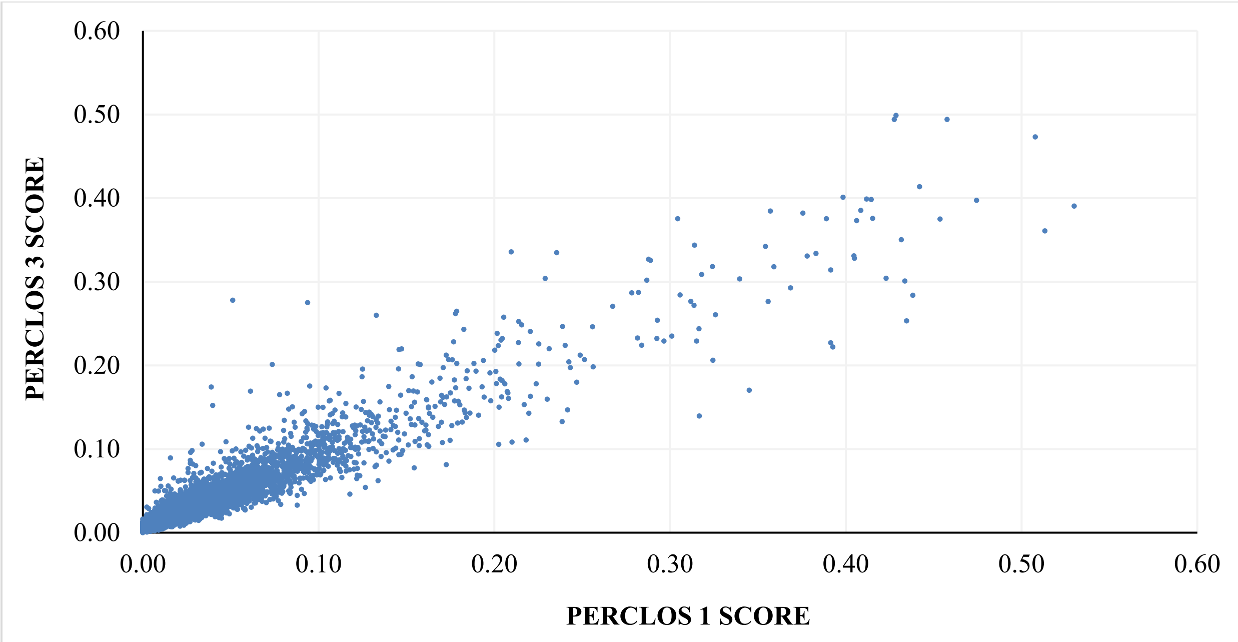

Figure 5. Graph. PERCLOS 1 score versus PERCLOS 3 score for truck BLs and SCEs.

Table 3. Truck linear mixed model solutions for fixed effects.

Effect	Estimate	Standard Error	*df*	*t*-value	*p*-value
Intercept	-0.0018	0.0005	157.40	-3.32	0.0011
PERCLOS 3 Score	1.0170	0.0068	997.20	149.97	<.0001

3.1.2 Comparison of PERCLOS Score Calculations as Binary Fatigue Values

BLs and SCEs were classified as fatigued if their PERCLOS score calculation met the fatigue threshold. BLs and SCEs with PERCLOS scores that did not meet the fatigue threshold were considered "not fatigued." The following analysis compares the fatigue determination rate by PERCLOS calculation type, event type, and vehicle type, to determine if BLs and SCEs were consistently classified as fatigued under both PERCLOS 1 and PERCLOS 3 calculations.

3.1.2.1 Motorcoach BLs and SCEs

Table 4 shows the count of motorcoach BLs by fatigue determination under PERCLOS 3 and PERCLOS 1 score calculations. Fatigue was identified in eight events using PERCLOS 3 and 11 events using PERCLOS 1. Table 5 presents the count and proportion of motorcoach BLs with matching or non-matching fatigue determination. Overall, a total of 99.48% of motorcoach BLs had matching fatigue determinations in their PERCLOS 3 and PERCLOS 1 score calculations (2,118 BLs). The table also presents the count and proportion of motorcoach BLs by match status, using PERCLOS 3 fatigue determination as the comparison standard. Of the eight motorcoach BLs marked fatigued using PERCLOS 3, half did not meet the fatigue threshold when PERCLOS 1 was used (4 BLs; 50.00%). Of the 2,121 motorcoach BLs marked not fatigued using PERCLOS 3, 0.33% met the fatigue threshold when PERCLOS 1 was used (7 BLs). The appendix includes a cross-table of counts and proportion of events by PERCLOS 3 and PERCLOS 1 fatigue determinations, for reference.

Table 4. Count of motorcoach BLs by fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

Fatigue Determination	PERCLOS 3 Count	PERCLOS 1 Count
Fatigued	8	11
Not Fatigued	2,121	2,118

Table 5. Count and proportion of motorcoach BLs by matched and unmatched fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

PERCLOS 3-PERCLOS 1 Match Status	Overall Count and Proportion	Count and Proportion of PERCLOS 3 Fatigued Events by Match Status	Count and Proportion of PERCLOS 3 Non-fatigued Events by Match Status
Matched Fatigue Determination	2,118 (99.48%)	4 (50.00%)	2,114 (99.67%)
Unmatched Fatigue Determination	11 (0.52%)	4 (50.00%)	7 (0.33%)

Table 6 shows the count of motorcoach SCEs by fatigue determination under PERCLOS 3 and PERCLOS 1 score calculations. Fatigue was identified in 14 events using PERCLOS 3 and 15 events using PERCLOS 1. Table 7 presents the count and proportion of motorcoach SCEs with matching or non-matching fatigue determination. Overall, over 99% of motorcoach SCEs had matching fatigue determinations in their PERCLOS 3 and PERCLOS 1 score calculations (1,050 SCEs; 99.15%). Of the 14 motorcoach SCEs marked fatigued using PERCLOS 3, more than one quarter did not meet the fatigue threshold when PERCLOS 1 was used (4 SCEs; 28.57%). Of the 1,045 motorcoach SCEs marked not fatigued using PERCLOS 3, 0.48% met the fatigue threshold when PERCLOS 1 was used (5 SCEs). As with the motorcoach BL data, a cross-table of counts and proportion of events by PERCLOS 3 and PERCLOS 1 fatigue determinations is included in the appendix for reference.

Table 6. Count of motorcoach SCEs by fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

Fatigue Determination	PERCLOS 3 Count	PERCLOS 1 Count
Fatigued	14	15
Not Fatigued	1,045	1,044

Table 7. Count and proportion of motorcoach SCEs by matched and unmatched fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

PERCLOS 3-PERCLOS 1 Match Status	Overall Count and Proportion	Count and Proportion of PERCLOS 3 Fatigued Events by Match Status	Count and Proportion of PERCLOS 3 Non-fatigued Events by Match Status
Matched Fatigue Determination	1,050 (99.15%)	10 (71.43%)	1,040 (99.52%)
Unmatched Fatigue Determination	9 (0.85%)	4 (28.57%)	5 (0.48%)

3.1.2.1 Truck BLs and SCEs

Table 8 shows the count of truck BLs by fatigue determination under PERCLOS 3 and PERCLOS 1 score calculations. Fatigue was identified in 80 events using PERCLOS 3 and 85 events using PERCLOS 1. Table 9 presents the count and proportion of truck BLs with matching or non-matching fatigue determination. Overall, a total of 97.43% of truck BLs had matching fatigue determinations in their PERCLOS 3 and PERCLOS 1 score calculations (2,086 BLs). Of the 80 truck BLs marked fatigued using PERCLOS 3, nearly one third did not meet the fatigue threshold when PERCLOS 1 was used (25 BLs; 31.25%). Of the 2,061 truck BLs marked not fatigued using PERCLOS 3, 1.46% met the fatigue threshold when PERCLOS 1 was used (30 BLs). As done for the motorcoach data, a cross-table of counts and proportion of events by PERCLOS 3 and PERCLOS 1 fatigue determinations has been included in the appendix for reference.

Table 8. Count of truck BLs by fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

Fatigue Determination	PERCLOS 3 Count	PERCLOS 1 Count
Fatigued	80	85
Not Fatigued	2,061	2,056

Table 9. Count and proportion of truck BLs by matched and unmatched fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

PERCLOS 3-PERCLOS 1 Match Status	Overall Count and Proportion	Count and Proportion of PERCLOS 3 Fatigued Events by Match Status	Count and Proportion of PERCLOS 3 Non-fatigued Events by Match Status
Matched Fatigue Determination	2,086 (97.43%)	55 (68.75%)	2,031 (98.54%)
Unmatched Fatigue Determination	55 (2.57%)	25 (31.25%)	30 (1.46%)

Table 10 shows the count of truck SCEs by fatigue determination under PERCLOS 3 and PERCLOS 1 score calculations. Fatigue was identified in 185 events using PERCLOS 3 and 182 events using PERCLOS 1. Table 11 presents the count and proportion of truck SCEs with matching or non-matching fatigue determination. Overall, over 95% of truck SCEs had matching fatigue determinations in their PERCLOS 3 and PERCLOS 1 score calculations (1,375 SCEs; 95.89%). Of the 185 truck SCEs marked fatigued using PERCLOS 3, approximately 1 of every 6 did not meet the fatigue threshold when PERCLOS 1 was used (31 SCEs; 16.76%). Of the 1,249 truck SCEs marked not fatigued using PERCLOS 3, 2.24% met the fatigue threshold when PERCLOS 1 was used (28 SCEs). The appendix includes a cross-table of counts and proportion of events by PERCLOS 3 and PERCLOS 1 fatigue determinations.

Table 10. Count of truck SCEs by fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

Fatigue Determination	PERCLOS 3 Count	PERCLOS 1 Count
Fatigued	185	182
Not Fatigued	1,249	1,252

Table 11. Count and proportion of truck SCEs by matched and unmatched fatigue determination using PERCLOS 3 and PERCLOS 1 calculations.

PERCLOS 3-PERCLOS 1 Match Status	Overall Count and Proportion	Count and Proportion of PERCLOS 3 Fatigued Events by Match Status	Count and Proportion of PERCLOS 3 Non-fatigued Events by Match Status
Matched Fatigue Determination	1,375 (95.89%)	154 (83.24%)	1,221 (97.76%)
Unmatched Fatigue Determination	59 (4.11%)	31 (16.76%)	28 (2.24%)

3.2 INVESTIGATING PREVALENCE AND RISK OF FATIGUE USING PERCLOS 1

Hammond et al. (2021) estimated drowsiness prevalence, SCE risk associated with drowsy driving, and the relationship between drowsy driving and secondary task involvement, using PERCLOS 3 score calculations. The following section reassesses these research questions using PERCLOS 1 score calculations. To answer these research questions, BLs and SCEs were marked as fatigued if the PERCLOS score calculation met the fatigue threshold; BLs and SCEs were marked as not fatigued if the PERCLOS score calculation did not meet the fatigue threshold. That is to say, the analyses use binary fatigue determinations based on PERCLOS score calculations.

3.2.1 Prevalence of Fatigue

In Hammond et al. (2021), BL data alone was used to estimate prevalence of fatigue in normal driving. The previous study found fatigue as measured with PERCLOS 3 in 0.39% of motorcoach BLs and 2.89% of truck BLs. The prevalence of fatigue as measured by PERCLOS 1 in BL data was found to be 0.52% for motorcoach data (11 BLs) and 3.95% for truck data (85 BLs). In the current study, the proportion of SCEs with PERCLOS 1 scores meeting the fatigue criteria was 1.42% of motorcoach SCEs (115 SCEs) and 12.69% of truck SCEs (182 SCEs).

3.2.1 Fatigue and SCE Involvement

The OR and 95% CI for SCE involvement when fatigued was calculated using PERCLOS 3 and PERCLOS 1. The PERCLOS 3 findings were originally published in the Hammond et al. (2021) report and indicated a significant risk of SCE involvement during fatigued driving for motorcoach drivers and truck drivers. Table 12 presents the OR and 95% CI for the odds of SCE involvement for fatigued driving compared to non-fatigued driving for motorcoach drivers. As seen in the table, the calculations using PERCLOS 1 showed no significant difference in the odds of SCE involvement. For motorcoach drivers, the finding using PERCLOS 1 was different from the finding using PERCLOS 3, which did find that the odds of SCE involvement significantly increase when fatigued.

Table 12. Motorcoach OR and corresponding 95% CI calculation for SCE involvement when fatigued, using PERCLOS 3 and PERCLOS 1 calculations.

PERCLOS Calculation Type	OR	95% LCL	95% UCL
PERCLOS 3†	2.68*	1.14	6.31
PERCLOS 1	2.12	0.94	4.78

† *Calculations as reported in Hammond et al. (2021).*
* *Indicates statistical significance at alpha = 0.05*

Table 13 presents the analysis results for risk of SCE involvement during fatigued driving and non-fatigued driving for truck drivers. Using PERCLOS 1, the odds of SCE involvement when fatigued were 2.31 times the odds when non-fatigued; that is, driving while fatigued increased the risk of SCE involvement compared to driving while not fatigued. The PERCLOS 1 finding echoes, in value, direction, and significance, the PERCLOS 3 finding in the Hammond et al. (2021) report.

Table 13. Truck OR and corresponding 95% CI calculation for SCE involvement when fatigued, using PERCLOS 3 and PERCLOS 1 calculations.

PERCLOS Calculation Type	OR	95% LCL	95% UCL
PERCLOS 3	2.88*	2.10	3.94
PERCLOS 1	2.31*	1.69	3.15

† *Calculations as reported in Hammond et al. (2021).*
* *Indicates statistical significance at alpha = 0.05*

3.2.1 Fatigue and Secondary Task Involvement

The Hammond et al. (2021) study also investigated the relationship between driver fatigue and involvement in secondary tasks, in both BLs and SCEs. The first analysis included events with any secondary task involvement.

Figure 6 presents the rate of fatigue in all motorcoach events, SCEs, and BLs, for events with secondary task involvement and events without secondary task involvement. The figure includes calculations using PERCLOS 3 and PERCLOS 1. Across all motorcoach events, fatigue using PERCLOS 3 was observed in 0.65% of events with secondary task involvement and 0.71% of events without secondary task involvement. Fatigue using PERCLOS 1 was observed in 0.83% of events with secondary task involvement and 0.81% of events without secondary task involvement. Fatigue using PERCLOS 3 was observed in 1.14% of SCEs with secondary task involvement and 1.45% of SCEs without secondary task involvement. Fatigue using PERCLOS 1 was observed in 1.60% of SCEs with secondary task involvement and 1.29% of SCEs without secondary task involvement. Using PERCLOS 3, the motorcoach BLs included fatigue in 0.31% of BLs with secondary task involvement and 0.40% of BLs without secondary task involvement. Using PERCLOS 1, the motorcoach BLs included fatigue in 0.31% of BLs with secondary task involvement and 0.61% of BLs without secondary task involvement.

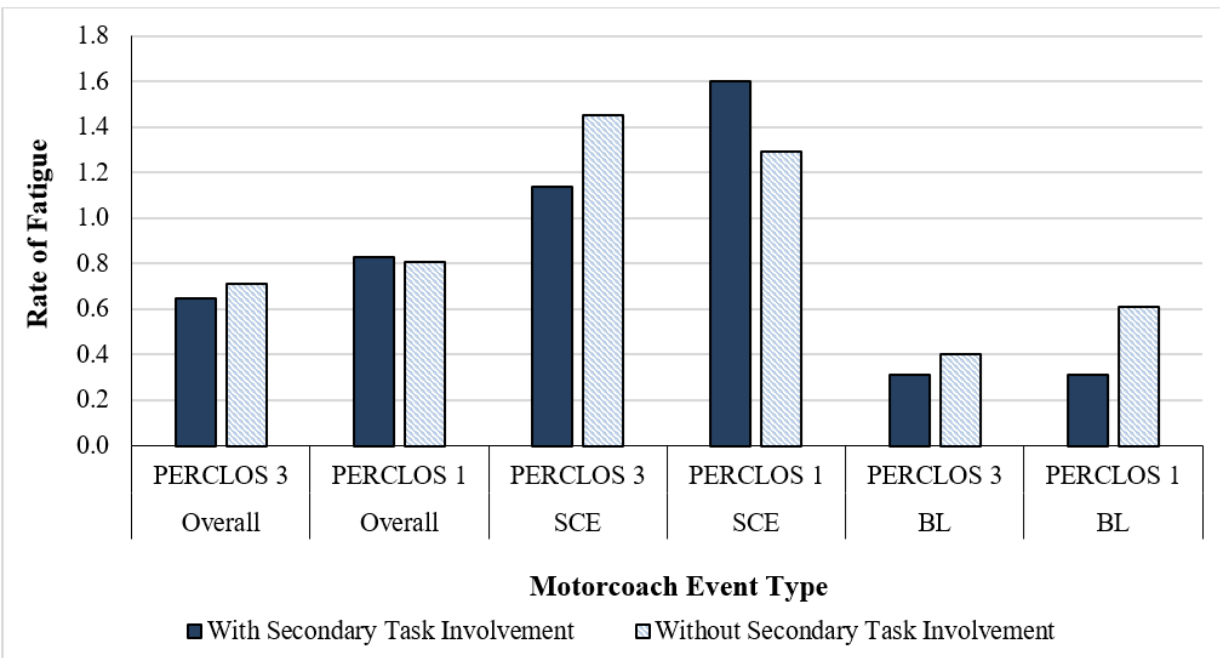

Figure 6. Chart. Rate of fatigue in motorcoach SCEs and BLs by secondary task involvement and PERCLOS calculation type.

Table 14 presents the OR and 95% CI comparing the odds of fatigue in motorcoach events (all, SCEs, and BLs) with and without secondary tasks, by PERCLOS calculation type. Analyses of each event type showed no statistically significant differences in fatigue rates between events with secondary task involvement and events without secondary task, regardless of PERCLOS calculation type. This finding was observed in each of the separate analyses for all motorcoach events overall, SCEs, and BLs.

Table 14. Motorcoach OR and corresponding 95% CI calculation for fatigue in SCEs and BLs by secondary task involvement and PERCLOS calculation type.

Event Type	PERCLOS Calculation Type	OR	95% LCL	95% UCL
Overall	PERCLOS 3	1.31	0.52	3.29
Overall	PERCLOS 1	1.20	0.52	2.76
SCE	PERCLOS 3	1.51	0.49	4.69
SCE	PERCLOS 1	0.86	0.31	2.44
BL	PERCLOS 3	1.39	0.28	7.01
BL	PERCLOS 1	2.53	0.53	12.07

An additional analysis investigated fatigue in specific secondary tasks, to determine if certain secondary tasks were associated with increased or decreased fatigue. Table 15 presents the count and percentage of motorcoach events with fatigue, by event type (BLs and SCEs) and secondary task involvement (with task present and with task not present). The motorcoach data included relatively low counts of observations with fatigue and observations with specific secondary tasks; therefore, the motorcoach driver data was not assessed for statistical significance. This was the case in the Hammond et al. (2021) study as well. In addition, secondary tasks without BLs or SCEs showing fatigue were excluded from the current table (included in the appendix for reference). No cell phone use tasks were observed with fatigue for motorcoach drivers.

Table 15. Motorcoach PERCLOS 1 fatigue in SCEs and BLs with specific secondary task involvement.

Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, showing Fatigue	Count (Percent) of Event Type with Task Not Present, showing Fatigue
Adjusting/monitoring other devices integral to vehicle	BL	0 (0.00%)	11 (0.52%)
Adjusting/monitoring other devices integral to vehicle	SCE	1 (3.85%)	14 (1.36%)
External distraction	BL	0 (0.00%)	11 (0.55%)
External distraction	SCE	1 (1.05%)	14 (1.45%)
Eating	BL	0 (0.00%)	11 (0.52%)
Eating	SCE	1 (4.55%)	14 (1.35%)
Other personal hygiene	BL	1 (6.25%)	10 (0.47%)
Other personal hygiene	SCE	1 (4.00%)	14 (1.35%)

Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, showing Fatigue	Count (Percent) of Event Type with Task Not Present, showing Fatigue
Talking/singing	BL	0 (0.00%)	11 (0.55%)
Talking/singing	SCE	2 (2.50%)	13 (1.33%)
Reaching for object	BL	0 (0.00%)	11 (0.52%)
Reaching for object	SCE	1 (4.17%)	14 (1.35%)

Figure 7 presents the rate of fatigue in all truck events, SCEs, and BLs, for events with secondary task involvement and events without secondary task involvement. The figure includes calculations using PERCLOS 3 and PERCLOS 1. Across all truck events, fatigue using PERCLOS 3 was observed in 6.74% of events with secondary task involvement and 8.09% of events without secondary task involvement. Fatigue using PERCLOS 1 was observed in 6.91% of events with secondary task involvement and 8.03% of events without secondary task involvement. Fatigue using PERCLOS 3 was observed in 11.13% of SCEs with secondary task involvement and 14.93% of SCEs without secondary task involvement. Fatigue using PERCLOS 1 was observed in 10.73% of SCEs with secondary task involvement and 14.93% of SCEs without secondary task involvement. Using PERCLOS 3, the truck BLs included fatigue in 3.49% of BLs with secondary task involvement and 3.96% of BLs without secondary task involvement. Using PERCLOS 1, the truck BLs included fatigue in 4.07% of BLs with secondary task involvement and 3.87% of BLs without secondary task involvement.

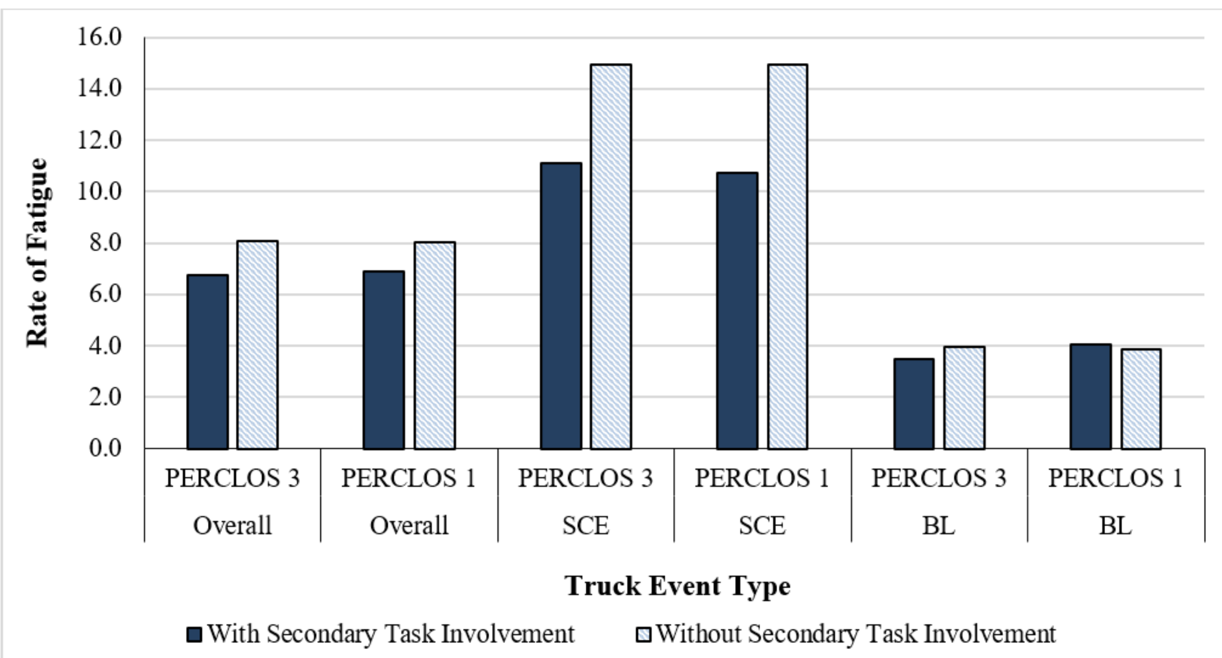

Figure 7. Chart. Rate of fatigue in truck SCEs and BLs by secondary task involvement and PERCLOS calculation type.

Table 16 presents the OR and 95% CI comparing the odds of fatigue in truck events (all, SCEs, and BLs) with and without secondary tasks, by PERCLOS calculation type. Analyses of each event type showed no statistically significant differences in fatigue rates between events with secondary task involvement and events without secondary task, regardless of PERCLOS calculation type. This finding was observed in each of the separate analyses for all truck events overall, SCEs, and BLs.

Table 16. Truck OR and corresponding 95% CI calculation for fatigue in SCEs and BLs by secondary task involvement and PERCLOS calculation type.

Event Type	PERCLOS Calculation Type	OR	95% LCL	95% UCL
Overall	PERCLOS 3	1.29	0.97	1.72
Overall	PERCLOS 1	1.26	0.95	1.67
SCE	PERCLOS 3	1.27	0.87	1.85
SCE	PERCLOS 1	1.42	0.97	2.09
BL	PERCLOS 3	1.19	0.75	1.91
BL	PERCLOS 1	0.97	0.62	1.52

A follow-up analysis investigated fatigue in specific secondary tasks, to determine if certain secondary tasks were associated with increased or decreased fatigue. Table 17 presents the count and percentage of truck events with PERCLOS 1 fatigue, by event type (BLs and SCEs) and secondary task involvement (with task present and with task not present). Secondary tasks without BLs or SCEs showing fatigue were excluded from the current table (included in the appendix for reference). Hammond et al. (2021) includes truck events with PERCLOS 3 fatigue, by event type and secondary task involvement (see report tables 85 and 86 for SCE and BL results, respectively).

The truck data was assessed for statistically significant differences in PERCLOS 1 fatigue in events with the task present and events without the task present. The resulting OR and 95% CI are included in the appendix. To stay consistent with the Hammond et al. 2021 report, the ORs compare the odds of fatigued driving in events *without* the task present to events *with* the task present. PERCLOS 1 fatigued driving was more likely to be observed in SCEs where the driver was removing/adjusting clothing [OR = 0.26, 95% CI = (0.08, 0.83)], compared to SCEs where the driver was not performing the task. PERCLOS 1 fatigued driving was less likely to be observed in SCEs where the driver was externally distracted [OR = 2.71, 95% CI = (1.32, 5.57)], compared to SCEs where the driver was not externally distracted. These results are similar in significance and direction to the findings using PERCLOS 3, included in Tables 85 and 86 of the Hammond et al. (2021) report. PERCLOS 1 fatigued driving was more likely to be observed in SCEs where the driver was dancing [OR = 0.23, 95% CI = (0.06, 0.80)]; this observation was not found using PERCLOS 3 fatigue in the Hammond et al. (2021) study. No significant differences in fatigue by secondary task engagement were found for BLs, using PERCLOS 1 or PERCLOS 3.

Table 17. Truck PERCLOS 1 fatigue in SCEs and BLs with specific secondary task involvement.

Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, showing Fatigue	Count (Percent) of Event Type with Task Not Present, showing Fatigue
Adjusting/monitoring other devices integral to vehicle	BL	0 (0.00%)	85 (3.99%)
Adjusting/monitoring other devices integral to vehicle	SCE	2 (6.45%)	180 (12.83%)
Adjusting instrument panel	BL	8 (6.25%)	77 (3.83%)
Adjusting instrument panel	SCE	9 (12.86%)	173 (12.68%)
Personal grooming	BL	1 (2.00%)	84 (4.02%)
Personal grooming	SCE	3 (12.00%)	179 (12.70%)
Dancing	BL	4 (10.00%)	81 (3.86%)
Dancing*	SCE	7 (46.67%)	175 (12.33%)
External distraction	BL	12 (4.29%)	73 (3.92%)
External distraction*	SCE	10 (5.32%)	172 (13.80%)
Drinking from container	BL	0 (0.00%)	85 (4.03%)
Drinking from container	SCE	1 (5.00%)	181 (12.80%)
Eating	BL	2 (2.38%)	83 (4.04%)
Eating	SCE	7 (9.86%)	175 (12.84%)
Electronic dispatching device	BL	3 (6.25%)	82 (3.92%)
Electronic dispatching device	SCE	2 (5.00%)	180 (12.91%)
Smoking-related: Reaching, lighting, extinguishing, interact	BL	0 (0.00%)	85 (3.98%)
Smoking-related: Reaching, lighting, extinguishing, interact	SCE	1 (20.00%)	181 (12.67%)
Other electronic device	BL	0 (0.00%)	85 (3.99%)
Other electronic device	SCE	1 (6.67%)	181 (12.76%)
Other personal hygiene	BL	4 (8.16%)	81 (3.87%)
Other personal hygiene	SCE	13 (28.89%)	169 (12.17%)
Reaching for food- or drink-related object	BL	2 (7.41%)	83 (3.93%)

Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, showing Fatigue	Count (Percent) of Event Type with Task Not Present, showing Fatigue
Reaching for food- or drink-related object	SCE	3 (8.33%)	179 (12.80%)
Removing/adjusting clothing	BL	1 (9.09%)	84 (3.94%)
Removing/adjusting clothing*	SCE	8 (42.11%)	174 (12.30%)
Tobacco use	BL	0 (0.00%)	85 (3.99%)
Tobacco use	SCE	1 (12.50%)	181 (12.69%)
Talking/singing	BL	7 (4.70%)	78 (3.92%)
Talking/singing	SCE	10 (14.29%)	172 (12.61%)
Smoking-related: Cigarette in hand or mouth	BL	4 (6.90%)	81 (3.89%)
Smoking-related: Cigarette in hand or mouth	SCE	3 (12.00%)	179 (12.70%)
Reaching for object	BL	1 (5.88%)	84 (3.95%)
Reaching for object	SCE	12 (16.44%)	170 (12.49%)

Table 18 presents the count and percentage of truck events with PERCLOS 1 fatigue by cell-phone-related secondary task involvement (with task present and with task not present). For each secondary task, the table includes rows by event type (SCEs and BLs). PERCLOS 3 fatigue in these secondary tasks is presented in Hammond et al. (2021) (see report Tables 85 and 86 for SCE and BL results, respectively). Very few SCEs and BLs with cell-phone-related secondary tasks also showed PERCLOS 1 fatigue. Hands-free talking/listening events showed PERCLOS 1 fatigue in two BLs (1.71%) and one SCE (2.04%). PERCLOS 1 fatigue was observed in 4.10% of BLs and 13.07% of SCEs without hands-free talking/listening. No significant differences in PERCLOS 1 fatigue by cell-phone-related secondary task engagement were found for BLs or SCEs. However, in Hammond et al. (2021), PERCLOS 3 fatigue was significantly lower for BLs and SCEs with hands-free call via headset/earpiece or hands-free talking/listening.

Table 18. Truck PERCLOS 1 fatigue in SCEs and BLs with specific cell-phone-related secondary task involvement.

Cell-phone-related Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, showing Fatigue	Count (Percent) of Event Type with Task Not Present, showing Fatigue
Cell phone: Hand-held browsing	BL	0 (0.00%)	85 (4.00%)
Cell phone: Hand-held browsing	SCE	2 (3.92%)	180 (13.02%)
Cell phone: Hand-held dialing	BL	0 (0.00%)	85 (3.97%)
Cell phone: Hand-held dialing	SCE	0 (0.00%)	182 (12.69%)

Cell-phone-related Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, showing Fatigue	Count (Percent) of Event Type with Task Not Present, showing Fatigue
Cell phone: Holding	BL	0 (0.00%)	85 (3.98%)
Cell phone: Holding	SCE	0 (0.00%)	182 (12.75%)
Cell phone: Locate/reach/answer	BL	0 (0.00%)	85 (3.98%)
Cell phone: Locate/reach/answer	SCE	0 (0.00%)	182 (12.75%)
Cell phone: Hand-held talking/listening	BL	0 (0.00%)	85 (3.99%)
Cell phone: Hand-held talking/listening	SCE	0 (0.00%)	182 (12.70%)
Cell phone: Hand-held texting	BL	0 (0.00%)	85 (3.97%)
Cell phone: Hand-held texting	SCE	0 (0.00%)	182 (12.74%)
Cell phone; Hands-free call via headset/earpiece	BL	2 (1.74%)	83 (4.10%)
Cell phone; Hands-free call via headset/earpiece	SCE	1 (2.08%)	181 (13.06%)
Cell phone: Hands-free call via speaker phone	BL	0 (0.00%)	85 (3.97%)
Cell phone: Hands-free call via speaker phone	SCE	0 (0.00%)	182 (12.70%)
Cell phone: Hands-free talking/listening	BL	2 (1.71%)	83 (4.10%)
Cell phone: Hands-free talking/listening	SCE	1 (2.04%)	181 (13.07%)

3.3 USING ORD TO SCREEN EVENTS FOR PERCLOS REDUCTION

The final analysis investigated if and how ORD and PERCLOS fatigue reduction can be leveraged to assess fatigue in truck and motorcoach naturalistic driving data. The goal was to determine if ORD, which is a more subjective method, could be used as a screening tool to identify the portion of events that show fatigue, which should then undergo PERCLOS reduction for a more objective score.

To begin, it is important to understand the distribution of ORD scores by rating category observed in the full dataset. The count and percentage of events (BL and SCE together) by ORD rating category and vehicle type are presented in Table 19. Motorcoach events included 20.15% rated “not drowsy,” 50.77% rated “slightly drowsy,” 26.41% rated “moderately drowsy,” 2.53% rated “very drowsy,” and 0.14% rated “extremely drowsy.” Truck events included 2.50% “not drowsy,” 40.13% “slightly drowsy,” 40.30% “moderately drowsy,” 14.23% “very drowsy,” and 2.83% “extremely drowsy.” In Hammond et al. (2021), the analyses assessed ORD rating categories as combined into three ORD rating groups: (1) not or slightly drowsy, (2), moderately drowsy, and (3) very or extremely drowsy.

Table 19. Count and percentage of events by ORD rating and vehicle type.

ORD Rating Category	ORD Rating Range	Motorcoach Event Count	Motorcoach Event Percent	Truck Event Count	Truck Event Percent
Not Drowsy	0 – 12.49	589	20.15%	75	2.50%
Slightly Drowsy	12.50 – 37.49	1,484	50.77%	1,204	40.13%
Moderately Drowsy	37.50 – 62.49	772	26.41%	1,209	40.30%
Very Drowsy	62.50 – 87.49	74	2.53%	427	14.23%
Extremely Drowsy	87.50 – 100	4	0.14%	85	2.83%

3.3.1 Identifying an ORD Rating Score Interval for Targeted PERCLOS Reduction

The next step in identifying an ORD rating score interval for targeted PERCLOS reduction was to understand the distribution of ORD ratings for events marked as fatigued using PERCLOS 3 and PERCLOS 1 score calculations.

Figure 9 shows the distribution of ORD rating groups for BLs and SCEs marked fatigued using PERCLOS 3 and PERCLOS 1 score calculations. In the truck data, 95.88% of PERCLOS 1 fatigued events were scored moderately drowsy or higher on the ORD scale (including 24.28% scored moderately drowsy and 71.60% rated very or extremely drowsy). Over 96% of truck PERCLOS 3 fatigued events received ORD ratings of moderately drowsy or higher, including 72.35% scored very or extremely drowsy and 23.46% scored moderately drowsy. In the motorcoach data, 91.67% of PERCLOS 1 fatigued events received ORD ratings of moderately drowsy or higher (including 62.50% scored moderately drowsy and 29.17% scored very or extremely drowsy). Nearly 86% of motorcoach PERCLOS 3 fatigued events received ORD ratings of moderately drowsy or higher, including 52.38% scored moderately drowsy and 33.33% scored very or extremely drowsy.

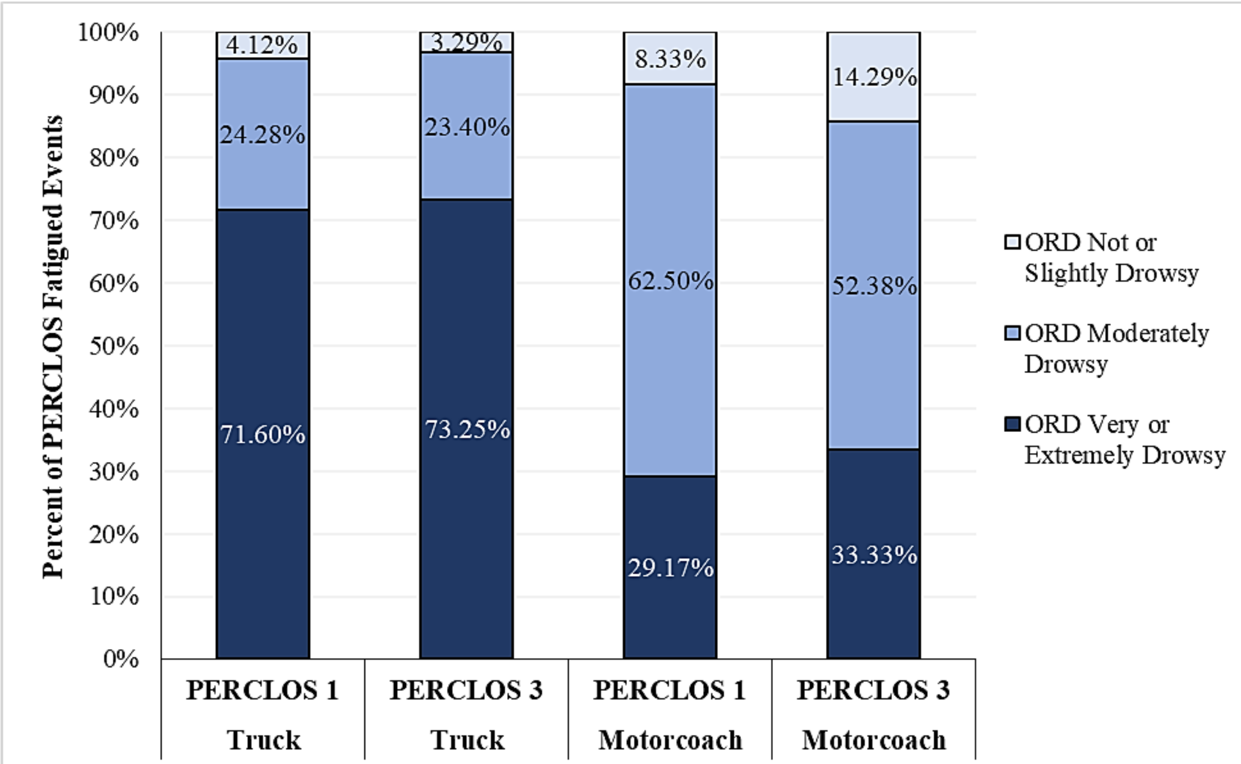

Figure 8. Chart. Distribution of PERCLOS 3 and 1 fatigued events by the ORD rating groups used in Hammond et al. (2021).

Table 20 further breaks down the number and proportion of PERCLOS fatigued events by ORD rating level for motorcoach events overall, SCEs, and BLs. The table includes counts of fatigued events using PERCLOS 3 and PERCLOS 1 score calculations. As seen in the table, no PERCLOS 3 or PERCLOS 1 fatigued events received an ORD "not drowsy" rating. For all event types overall, SCEs, and BLs, approximately 14.29% of fatigued PERCLOS 3 events were rated "slightly drowsy." Over 50% of all PERCLOS 3 fatigued events were rated "moderately drowsy" and a third were rated "very drowsy." No PERCLOS 3 fatigued events were rated "extremely drowsy." For PERCLOS 1 fatigued events, no BLs and 13.33% of SCEs were rated "slightly drowsy." Over 62% of all PERCLOS 1 fatigued events were rated "moderately drowsy," a quarter were rated "very drowsy," and one SCE was rated "extremely drowsy" (4.17% of PERCLOS 1 fatigued events overall).

Table 20. Count and proportion of PERCLOS 3 and PERCLOS 1 fatigued motorcoach events by ORD rating level.

Event Type	ORD Rating	Total Events in ORD Rating Category	PERCLOS 3 Fatigued Count	PERCLOS 3 Fatigued Proportion	PERCLOS 1 Fatigued Count	PERCLOS 1 Fatigued Proportion
Overall	Not Drowsy	589	0	0.00%	0	0.00%
Overall	Slightly Drowsy	1,484	3	14.29%	2	8.33%
Overall	Moderately Drowsy	772	11	52.38%	15	62.50%
Overall	Very Drowsy	74	7	33.33%	6	25.00%
Overall	Extremely Drowsy	4	0	0.00%	1	4.17%
SCE	Not Drowsy	273	0	0.00%	0	0.00%
SCE	Slightly Drowsy	519	2	14.29%	2	13.33%
SCE	Moderately Drowsy	226	7	50.00%	8	53.33%
SCE	Very Drowsy	34	5	35.71%	4	26.67%
SCE	Extremely Drowsy	3	0	0.00%	1	6.67%
BL	Not Drowsy	316	0	0.00%	0	0.00%
BL	Slightly Drowsy	965	1	14.29%	0	0.00%
BL	Moderately Drowsy	546	4	57.14%	7	77.78%
BL	Very Drowsy	40	2	28.57%	2	22.22%
BL	Extremely Drowsy	1	0	0.00%	0	0.00%

Table 21 shows the number and proportion of PERCLOS fatigued truck events by ORD rating level and event type (overall, BL, SCE). The table includes counts of fatigued events using PERCLOS 3 and PERCLOS 1 score calculations. As for the motorcoach data, no PERCLOS 3 or PERCLOS 1 fatigued truck events received an ORD "not drowsy" rating. Less than 4% of all PERCLOS 3 fatigued events and less than 5% of all PERCLOS 1 fatigued events were rated "slightly drowsy." Approximately one quarter of all PERCLOS 3 and PERCLOS 1 fatigued events were rated "moderately drowsy." This ORD rating was observed in less than 17% of PERCLOS 3 or PERCLOS 1 fatigued SCEs and nearly half of PERCLOS 3 or PERCLOS 1 fatigued BLs. Over 50% of all PERCLOS 3 and PERCLOS 1 fatigued events were rated "very drowsy." More than 25% of PERCLOS 3 or PERCLOS 1 fatigued SCEs and about 5% of PERCLOS 3 or PERCLOS 1 fatigued BLs were rated "extremely drowsy."

Table 21. Count and proportion of PERCLOS 3 and PERCLOS 1 fatigued truck events by ORD rating level.

Event Type	ORD Rating	Total Events in ORD Rating Category	PERCLOS 3 Fatigued Count	PERCLOS 3 Fatigued Proportion	PERCLOS 1 Fatigued Count	PERCLOS 1 Fatigued Proportion
Overall	Not Drowsy	75	0	0.00%	0	0
Overall	Slightly Drowsy	1,204	8	3.29%	10	4.12
Overall	Moderately Drowsy	1,209	57	23.46%	59	24.28
Overall	Very Drowsy	427	126	51.85%	126	51.85
Overall	Extremely Drowsy	85	52	21.40%	48	19.75%
SCE	Not Drowsy	44	0	0.00%	0	0.00%
SCE	Slightly Drowsy	608	6	3.24%	7	3.85%
SCE	Moderately Drowsy	452	29	15.68%	30	16.48%
SCE	Very Drowsy	253	101	54.59%	99	54.40%
SCE	Extremely Drowsy	77	49	26.49%	46	25.27%
BL	Not Drowsy	31	0	0.00%	0	0.00%
BL	Slightly Drowsy	596	2	3.45%	3	4.92%
BL	Moderately Drowsy	757	28	48.28%	29	47.54%
BL	Very Drowsy	174	25	43.10%	27	44.26%
BL	Extremely Drowsy	8	3	5.17%	2	3.28%

All but one PERCLOS fatigued event with ORD ratings of "slightly drowsy" had ORD rating scores of 27 or higher (one truck SCE had a score of 19). If an ORD rating score of at least 27 was set as the cutoff for performing PERCLOS reduction, 2,815 events from the study would not need PERCLOS reduction. These events included 1,683 motorcoach events (588 SCEs, 1,095 BLs) and 1,132 truck events (283 SCEs, 849 BLs). The cutoff score could be set slightly lower to include a small buffer. If the ORD rating score cutoff was lowered to at least 25, 2,577 events would not need PERCLOS reduction. These events included 1,532 motorcoach events (536 SCEs, 996 BLs) and 1,045 truck events (240 SCEs, 805 BLs). Of the 6,763 events included in the current study, 3,948 (58.38%) would receive PERCLOS reduction with an ORD rating score threshold of at least 27, and 4,186 (61.90%) would receive PERCLOS reduction with an ORD rating score threshold of at least 25.

3.3.2 Comparison of Fatigue Reduction Options for Time and Cost

Table 22 presents estimated event reduction rates for each fatigue assessment method. The following reduction rates assume that the video is being collected at 15 Hz (15 frames per second), which was the rate used in SHRP 2. If the face video is collected at a higher hertz rate, then the PERCLOS reduction rates will likely be slower. ORD reduction averages 10 events per hour, with each event reduced by three individual researchers. PERCLOS 3 reduction averages 2.5 events per hour, with each event reduced by one researcher. PERCLOS 1 reduction averages 7.1 events per hour, with each event reduced by one researcher. All fatigue reduction options require quality assurance (QA) review, which adds approximately 50% more time to the process.

Table 22. Estimates for event reduction rate by fatigue assessment method.

Fatigue Assessment Method	Reduction Rate per Reductionist	Method Required Number of Reductionists per Event	QA Rate
ORD	10 events/hour	3	50% of reduction time
PERCLOS 3	2.5 events/hour	1	50% of reduction time
PERCLOS 1	7.1 events/hour	1	50% of reduction time

Table 23 lists the total reduction time and cost for all fatigue reduction options, including the hybrid ORD and targeted PERCLOS options. The table assumes a full reduction of 6,763 events and a targeted PERCLOS reduction of 3,948 (ORD score threshold of 27) and 4,186 (ORD score threshold of 25) events. The cost estimates assume an hourly wage of $22, which accounts for a buffer in case wage rates increase during the reduction period.

For ORD reduction, all 6,763 events are each rated by three researchers and the events undergo additional QA review for a total of 3,043.35 hours. The cost for ORD reduction for the full event dataset would be approximately $66,953.70. Performing PERCLOS 3 for all events would take 4,057.80 hours and cost an estimated $89,271.60. Performing PERCLOS 1 for all events would take 1,428.80 hours and cost approximately $31,433.66. If a study took the same approach as Hammond et al. (2021) and performed ORD and PERCLOS 3 for all events, the total cost is estimated at $156,225.30. If ORD and PERCLOS 1 were performed for all events, the total cost is estimated at $98,387.36. Performing ORD for all events, followed by a targeted PERCLOS 3 reduction of events above ORD rating score thresholds of 25 or 27 would cost $119,071.70 or $122,213.30, respectively. ORD for all events followed by targeted PERCLOS 1 reduction events above ORD rating score thresholds of 25 or 27 would cost $85,307.96 or $86,414.16, respectively.

Table 23. Reduction time and cost for all fatigue reduction options (all ORD only, all PERCLOS 3 only, all PERCLOS 1 only, hybrid all ORD and PERCLOS, and a hybrid ORD and targeted PERCLOS option).

Fatigue Reduction Option	ORD Rating Score Fatigue Threshold	Total Reduction Time with QA (hours)	Total Reduction Cost
All ORD	n/a	3,043.55	$66,953.70
All PERCLOS 3	n/a	4,057.80	$89,271.60
All PERCLOS 1	n/a	1,428.80	$31,433.66
All ORD + All PERCLOS 3	n/a	7,101.35	$156,225.30

Fatigue Reduction Option	ORD Rating Score Fatigue Threshold	Total Reduction Time with QA (hours)	Total Reduction Cost
All ORD + All PERCLOS 1	n/a	4,472.35	$98,387.36
All ORD + Targeted PERCLOS 3	27	5,412.35	$119,071.70
All ORD + Targeted PERCLOS 3	25	5,555.15	$122,213.30
All ORD + Targeted PERCLOS 1	27	3,877.63	$85,307.96
All ORD + Targeted PERCLOS 1	25	3,927.92	$86,414.16

The option with the lowest time and cost budget is PERCLOS 1 for all events. Although not included as a factor in the budget assessment here, the use of PERCLOS 1 was found to increase the sample size of events with available data. This increase in event sample size would require additional reduction at cost but could be a benefit for expanding analysis options.

It is also important to consider that ORD can provide critical insight into driver drowsiness expressed through other mannerisms besides closed eyes and allows events to be assessed for a range of drowsiness. In fact, a review of events that did not meet the PERCLOS fatigue threshold but did show ORD drowsiness showed varied and validated drowsiness behaviors such as yawning, face/eye/neck rubbing, restlessness, lack of visual scanning, and rapid blinking. Therefore, ORD is an important fatigue reduction approach to consider. A fatigue reduction approach of performing ORD for all events plus targeted PERCLOS at the designated fatigue threshold costs more than performing PERCLOS alone for all events. The ORD rating score threshold is too low to gain an advantage with the higher reduction rate. However, the targeted approach does reduce cost compared to performing ORD and PERCLOS for all events (the approach taken in Hammond et al., 2021).

Table 24 compares the reduction costs for ORD and targeted PERCLOS options to the approach of ORD and PERCLOS for all events. To be conservative, the table presents the proportion of reduction cost calculations using a targeted ORD rating score fatigue threshold of 25. A targeted approach using PERCLOS 3 is 78.23% of the cost of all events receiving ORD and PERCLOS 3 reduction. A targeted approach using PERCLOS 1 is 87.83% of the cost of all events receiving ORD and PERCLOS 1 reduction. Finally, a targeted approach using PERCLOS 1 (the most cost-efficient option) is 55.31% of the cost of all events receiving ORD and PERCLOS 3 reduction (the highest cost option).

Table 24. Proportion of reduction cost for ORD and targeted PERCLOS option compared to all ORD and PERCLOS option.

Proposed Fatigue Reduction Option	Comparison Fatigue Reduction Option	Proportion of Reduction Cost
All ORD + Targeted PERCLOS 3 at ORD Threshold 25	All ORD + All PERCLOS 3	78.23%
All ORD + Targeted PERCLOS 1 at ORD Threshold 25	All ORD + All PERCLOS 1	87.83%
All ORD + Targeted PERCLOS 1 at ORD Threshold 25	All ORD + All PERCLOS 3	55.31%

CHAPTER 4. CONCLUSIONS

Drowsy and fatigued driving is a critical problem, resulting in thousands of crashes and fatalities every year. Naturalistic driving research provides critical insight on the characteristics of drowsy driving and the frequency and severity with which it occurs. Two methods of assessing driver drowsiness have been validated for use with naturalistic driving data. ORD is a more subjective assessment, and manual PERCLOS is a more objective assessment. Each of these drowsiness assessment tools has strengths. ORD assesses driver drowsiness using a multitude of features, including driver appearance, behaviors, and mannerisms (Wiegand, McClafferty, McDonald, & Hanowski, 2009). In addition, each assessed event is reviewed and scored by three trained researchers. Manual PERCLOS scores drowsiness based on eye closure alone and is a measure of the percentage of time a driver's eyes are "80 to 100 percent" closed (Wierwille & Ellsworth, 1994). Each assessed event is reduced by one trained researcher.

The Naturalistic Driving Study (Hammond et al., 2021) reduced naturalistic driving data from commercial drivers of trucks and motorcoach buses and included both ORD and PERCLOS 3 reduction for a subset of events. In Hammond et al. (2021), researchers were able to examine driver drowsiness patterns and risk using both ORD and PERCLOS 3 ratings. In the current study, researchers further compared naturalistic driving data drowsiness assessment measures for the same subset of events.

The use of PERCLOS 1 can increase the available event sample size for analysis. In the current study, a substantial number of events that did not meet PERCLOS 3 reduction criteria did meet PERCLOS 1 reduction criteria. The sample size of events with PERCLOS data increased by 8.94% when using PERCLOS 1. In a naturalistic driving study focused on light vehicles, the use of PERCLOS 1 in place of PERCLOS 3 increased the event sample size by 19.02% (adding 112 more crashes to a sample size of 589 crashes with PERCLOS 3 data; Owens et al., 2018).

As PERCLOS 1 is calculated from a subset of time used to calculate PERCLOS 3, it is not surprising that a strong relationship was found between the scores. Over 99% of motorcoach BLs and SCEs had matching fatigue determination in their PERCLOS 3 and PERCLOS 1 scores. The same analysis of truck events found matching fatigue determinations between PERCLOS scores for more than 95% of truck BLs and SCEs. However, there were events that met the fatigue threshold for one score and not the other; therefore, there is a risk of capturing different events based on the PERCLOS method used.

Fatigue prevalence in BLs was also slightly different based on the PERCLOS method. Using PERCLOS 3, Hammond et al. (2021) found fatigue in 0.39% of motorcoach BLs and 2.89% of truck BLs. In the current study, fatigue as measured using PERCLOS 1 was found in 0.52% of motorcoach BLs and 3.95% of truck BLs. Fatigue prevalence in SCEs as measured using PERCLOS 1 was 1.42% for motorcoach SCEs and 12.69% for truck SCEs. In a separate study of the motorcoach data, which used ORD to measure driver drowsiness, high levels of drowsiness were observed in approximately 1% of motorcoach driving epochs (Hammond et al., 2016). A 2006 naturalistic driving study of light vehicle drivers found that drowsiness occurred in 2.2% of BLs (Klauer et al., 2006). A 2016 naturalistic driving study of light vehicle drivers found similar rates drowsiness in BLs (1.57%; Dingus et al., 2016). In crashes by light vehicle drivers, Owens et al. (2018) estimated fatigue prevalence using PERCLOS 3 and PERCLOS 1. The PERCLOS 1 event set did include additional events outside of the PERCLOS 3 event set and so a direct comparison cannot be made between the two PERCLOS methods. The study estimated fatigue prevalence at 9.5% of crashes evaluated with PERCLOS 3 and 8.8% of crashes evaluated with PERCLOS 1.

The current study investigated the risk of SCE involvement when fatigued and rates of fatigue in events with secondary tasks, using PERCLOS 1 to measure fatigue. These analyses were originally performed in Hammond et al. (2021) using PERCLOS 3 to measure fatigue. Truck drivers showed statistically significant increased risk of SCE involvement when fatigued, regardless of PERCLOS method used to measure fatigue. When PERCLOS 1 was used to measure fatigue, no significant difference was found in the odds of SCE involvement for fatigued and non-fatigued motorcoach drivers. This finding differed from the Hammond et al. (2021) finding, which found motorcoach drivers showed significantly increased odds of SCE involvement when fatigued. Increased risk of SCE or crash involvement when fatigued has been found in several driving studies. In a study of local/short-haul drivers, Hanowski (2000) found PERCLOS scores were higher during safety-related events caused by local, short-haul drivers compared to BL epochs. The Large Truck Crash Causation Study estimated the proportion of crashes involving fatigue to be approximately 13% (FMCSA, 2005). A 2006 naturalistic driving study of light vehicle drivers found driving while severely drowsy could increase risk of crash or near-crash involvement by more than 4.5 times (Dingus et al., 2006). A naturalistic study of light vehicles conducted in 2016 found drowsy driving was associated with a 3.4 times increased risk of crash involvement (Dingus et al., 2016).

The assessment of drowsiness measurement methods for reduction cost and time identified an opportunity to limit costs and obtain full, rich datasets using a targeted reduction approach. Performing ORD for all events and PERCLOS 1 for targeted events was approximately 55.31% of the cost of all events receiving ORD and PERCLOS 3 reduction (which is the highest cost option). Even performing PERCLOS 3, in place of PERCLOS 1, for targeted events reduced costs to 78.23% of the cost of all events receiving ORD and PERCLOS 3 reduction. It is important to note that each drowsiness measurement method has strengths. ORD can identify moments of fatigue across a wide range of drowsiness, using more behavioral indicators besides eye closures. PERCLOS can be used to identify fatigue using an objective approach. Fatigue identified using PERCLOS tends to be on the higher end of the drowsiness scale. The PERCLOS method has been found to miss moderate drowsiness or other expressions of drowsiness (Abe, 2023). PERCLOS 1 is the drowsiness measurement method with the lowest time and cost impact.

As researchers evaluate the best drowsiness measurement method for their study, it will be key to determine how the different methods will impact the range of drowsiness captured, the number of events to assess, and the time and monetary budget for fatigue reduction. Researchers may want to consider for what purpose they are assessing drowsiness and whether it is important to capture early stages of drowsiness and fatigue-fighting or fatigue-managing behaviors or to capture fatigue in more advanced stages. Drowsy driving continues to take lives, and research on fatigued driving is essential to reducing drowsy driving crashes.

4.1 LIMITATIONS

Fatigue as identified by PERCLOS thresholds is a very specific expression of fatigue, through eye closures. Although PERCLOS is a well-validated method to assess driver fatigue, it is likely to capture more severe drowsiness compared to the range of drowsiness captured through the ORD method. The number of events showing fatigue as measured through PERCLOS scores can be limited and therefore affect the ability to successfully assess instances of fatigue by stratified variables. An example of this in the current study is the limited analysis of secondary task involvement.

The PERCLOS method is also limited to instances where the driver's face is visible with good image quality. The field of drowsy driving detection is evolving as new technologies with the ability to detect fatigue in real time come into play and are validated through rigorous testing.

A further limitation to the analyses is the consideration of event counts with available, method-appropriate data in budgeting for ORD, PERCLOS 3, and PERCLOS 1. It would be possible to perform ORD for events that meet ORD data requirements, PERCLOS 3 for events that meet PERCLOS 3 data requirements (specifically, 3 minutes of video data), and PERCLOS 1 for events that meet PERCLOS 1 data requirements (1 minute of video data). The targeted approach could include both PERCLOS 3 and PERCLOS 1 reduction, based on each event's data availability. A future analysis could incorporate the expected rate of events that meet each drowsiness assessment measure's data requirements.

APPENDIX A. ADDITIONAL REFERENCE TABLES FOR ANALYSIS RESULTS

ADDITIONAL REFERENCE TABLES FOR "COMPARISON OF PERCLOS CALCULATIONS AS CONTINUOUS VALUES"

Table 25. Motorcoach BL PERCLOS 3 vs. PERCLOS 1 model solutions for fixed effects.

Effect	Estimate	Standard Error	*df*	*t*-value	*p*-value
Intercept	-0.00005	0.00030	115.00	-0.18	0.8565
PERCLOS 3 Score	0.99910	0.00947	993.30	105.55	<.0001

Table 26. Motorcoach SCE PERCLOS 3 vs. PERCLOS 1 model solutions for fixed effects.

Effect	Estimate	Standard Error	*df*	*t*-value	*p*-value
Intercept	0.0007	0.0005	170.60	1.34	0.1817
PERCLOS 3 Score	0.9011	0.0144	565.90	62.57	<.0001

Table 27. Truck BL PERCLOS 3 vs. PERCLOS 1 model solutions for fixed effects.

Effect	Estimate	Standard Error	*df*	*t*-value	*p*-value
Intercept	0.0002	0.0006	237.50	0.34	0.7378
PERCLOS 3 Score	0.9669	0.0101	752.80	95.62	<.0001

Table 28. Truck SCE PERCLOS 3 vs. PERCLOS 1 model solutions for fixed effects.

Effect	Estimate	Standard Error	*df*	*t*-value	*p*-value
Intercept	-0.0024	0.0010	107.50	-2.45	0.0161
PERCLOS 3 Score	1.0323	0.0099	348.30	104.29	<.0001

ADDITIONAL REFERENCE TABLES FOR "COMPARISON OF PERCLOS CALCULATIONS AS BINARY FATIGUE VALUES"

Table 29. Count and proportion of motorcoach BLs by fatigue status under PERCLOS 3 and PERCLOS 1 calculations.

Motorcoach BLs Fatigue Status	PERCLOS 1 Fatigued	PERCLOS 1 Not Fatigued
PERCLOS 3 Fatigued	4 (0.19%)	4 (0.19%)
PERCLOS 3 Not Fatigued	7 (0.33%)	2,114 (99.30%)

Table 30. Count and proportion of motorcoach SCEs by fatigue status under PERCLOS 3 and PERCLOS 1 calculations.

Motorcoach SCEs Fatigue Status	PERCLOS 1 Fatigued	PERCLOS 1 Not Fatigued
PERCLOS 3 Fatigued	10 (0.94%)	4 (0.38%)
PERCLOS 3 Not Fatigued	5 (0.47%)	1,040 (98.21%)

Table 31. Count and proportion of truck BLs by fatigue status under PERCLOS 3 and PERCLOS 1 calculations.

Truck BLs Fatigue Status	PERCLOS 1 Fatigued	PERCLOS 1 Not Fatigued
PERCLOS 3 Fatigued	55 (2.57%)	25 (1.17%)
PERCLOS 3 Not Fatigued	30 (1.40%)	2,031 (94.86%)

Table 32. Count and proportion of truck SCEs by fatigue status under PERCLOS 3 and PERCLOS 1 calculations.

Truck SCEs Fatigue Status	PERCLOS 1 Fatigued	PERCLOS 1 Not Fatigued
PERCLOS 3 Fatigued	154 (10.74%)	31 (2.16%)
PERCLOS 3 Not Fatigued	28 (1.95%)	1,221 (85.15%)

ADDITIONAL REFERENCE TABLES FOR "INVESTIGATING PREVALENCE AND RISK OF FATIGUE USING PERCLOS 1"

Table 33. Fatigued proportion of motorcoach events (all, SCEs, and BLs) by secondary task involvement.

Event Type	PERCLOS Calculation Type	Fatigued Proportion of Events with Secondary Task Involvement	Fatigued Proportion of Events without Secondary Task Involvement
Overall	PERCLOS 3	0.65%	0.71%
Overall	PERCLOS 1	0.83%	0.81%
SCE	PERCLOS 3	1.14%	1.45%
SCE	PERCLOS 1	1.60%	1.29%
BL	PERCLOS 3	0.31%	0.40%
BL	PERCLOS 1	0.31%	0.61%

Table 34. Fatigued proportion of truck events (all, SCEs, and BLs) by secondary task involvement.

Event Type	PERCLOS Calculation Type	Fatigued Proportion of Events with Secondary Task Involvement	Fatigued Proportion of Events without Secondary Task Involvement
Overall	PERCLOS 3	6.74%	8.09%
Overall	PERCLOS 1	6.91%	8.03%
SCE	PERCLOS 3	11.13%	14.93%
SCE	PERCLOS 1	10.73%	14.93%
BL	PERCLOS 3	3.49%	3.96%
BL	PERCLOS 1	4.07%	3.87%

Table 35. PERCLOS 1 fatigue in motorcoach SCEs and BLs with specific secondary task involvement (all secondary tasks listed).

Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, Showing Fatigue	Count (Percent) of Event Type with Task Not Present, Showing Fatigue
Adjusting/monitoring other devices integral to vehicle	BL	0 (0.00%)	11 (0.52%)
Adjusting/monitoring other devices integral to vehicle	SCE	1 (3.85%)	14 (1.36%)
Adjusting instrument panel	BL	0 (0.00%)	11 (0.52%)
Adjusting instrument panel	SCE	0 (0.00%)	15 (1.42%)
Personal grooming	BL	0 (0.00%)	11 (0.52%)
Personal grooming	SCE	0 (0.00%)	15 (1.45%)
Dancing	BL	0 (0.00%)	11 (0.52%)
Dancing	SCE	0 (0.00%)	15 (1.42%)
External distraction	BL	0 (0.00%)	11 (0.55%)
External distraction	SCE	1 (1.05%)	14 (1.45%)
Drinking from container	BL	0 (0.00%)	11 (0.52%)
Drinking from container	SCE	0 (0.00%)	15 (1.42%)
Eating	BL	0 (0.00%)	11 (0.52%)
Eating	SCE	1 (4.55%)	14 (1.35%)
Electronic dispatching device	BL	0 (0.00%)	11 (0.52%)
Electronic dispatching device	SCE	0 (0.00%)	15 (1.42%)
Smoking-related: Reaching, lighting, extinguishing	BL	0 (0.00%)	11 (0.52%)
Smoking-related: Reaching, lighting, extinguishing	SCE	0 (0.00%)	15 (1.42%)
Other electronic device	BL	0 (0.00%)	11 (0.52%)
Oher electronic device	SCE	0 (0.00%)	15 (1.43%)
Other personal hygiene	BL	1 (6.25%)	10 (0.47%)
Other personal hygiene	SCE	1 (4.00%)	14 (1.35%)
Passenger in adjacent seat	BL	0 (0.00%)	11 (0.52%)
Passenger in adjacent seat	SCE	0 (0.00%)	15 (1.42%)
Reaching for food- or drink-related object	BL	0 (0.00%)	11 (0.52%)
Reaching for food- or drink-related object	SCE	0 (0.00%)	15 (1.43%)
Reading	BL	0 (0.00%)	11 (0.52%)
Reading	SCE	0 (0.00%)	15 (1.42%)
Removing/adjusting clothing	BL	0 (0.00%)	11 (0.52%)
Removing/adjusting clothing	SCE	0 (0.00%)	15 (1.43%)
Tobacco use	BL	0 (0.00%)	11 (0.52%)
Tobacco use	SCE	0 (0.00%)	15 (1.42%)
Talking/singing	BL	0 (0.00%)	11 (0.55%)
Talking/singing	SCE	2 (2.50%)	13 (1.33%)
Smoking-related: Cigarette in hand or mouth	BL	0 (0.00%)	11 (0.52%)
Smoking-related: Cigarette in hand or mouth	SCE	0 (0.00%)	15 (1.42%)
Reaching for object	BL	0 (0.00%)	11 (0.52%)
Reaching for object	SCE	1 (4.17%)	14 (1.35%)

Table 36. PERCLOS 1 fatigue in motorcoach SCEs and BLs with specific cell phone-related secondary task involvement.

Cell-phone-related Secondary Task	Event Type	Count (Percent) of Event Type with Task Present, Showing Fatigue	Count (Percent) of Event Type with Task Not Present, Showing Fatigue
Cell phone: Hand-held browsing	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hand-held browsing	SCE	0 (0.00%)	15 (1.43%)
Cell phone: Hand-held dialing	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hand-held dialing	SCE	0 (0.00%)	15 (1.42%)
Cell phone: Holding	BL	0 (0.00%)	11 (0.52%)
Cell phone: Holding	SCE	0 (0.00%)	15 (1.42%)
Cell phone: Locate/reach/answer	BL	0 (0.00%)	11 (0.52%)
Cell phone: Locate/reach/answer	SCE	0 (0.00%)	15 (1.43%)
Cell phone: Hand-held talking/listening	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hand-held talking/listening	SCE	0 (0.00%)	15 (1.42%)
Cell phone: Hand-held texting	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hand-held texting	SCE	0 (0.00%)	15 (1.42%)
Cell phone: Hands-free call via headset/earpiece	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hands-free call via headset/earpiece	SCE	0 (0.00%)	15 (1.43%)
Cell phone: Hands-free call via speaker phone	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hands-free call via speaker phone	SCE	0 (0.00%)	15 (1.42%)
Cell phone: Hands-free talking/listening	BL	0 (0.00%)	11 (0.52%)
Cell phone: Hands-free talking/listening	SCE	0 (0.00%)	15 (1.43%)

Table 37. PERCLOS 1 fatigue OR and 95% CI in truck SCEs and BLs with specific secondary task involvement (all secondary tasks listed).

Secondary Task	Event Type	OR	95% LCL	95% UCL
Adjusting/monitoring other devices integral to vehicle	BL	-	-	-
Adjusting/monitoring other devices integral to vehicle	SCE	1.72	0.36	8.16
Adjusting instrument panel	BL	0.61	0.28	1.33
Adjusting instrument panel	SCE	1.02	0.47	2.24
Personal grooming	BL	1.49	0.20	11.37
Personal grooming	SCE	0.64	0.17	2.42
Dancing	BL	0.37	0.12	1.13
Dancing	SCE	0.23	0.06	0.80
External distraction	BL	1.01	0.53	1.93
External distraction	SCE	2.71	1.32	5.57
Drinking from container	BL	-	-	-
Drinking from container	SCE	2.73	0.34	22.19
Eating	BL	1.85	0.44	7.81
Eating	SCE	1.35	0.57	3.20
Electronic dispatching device	BL	0.53	0.16	1.83
Electronic dispatching device	SCE	2.99	0.66	13.52
Smoking-related: Reaching, lighting, extinguishing	BL	-	-	-
Smoking-related: Reaching, lighting, extinguishing	SCE	1.52	0.05	47.87
Other electronic device	BL	-	-	-
Other electronic device	SCE	1.56	0.19	13.24
Other personal hygiene	BL	0.58	0.19	1.76
Other personal hygiene	SCE	0.65	0.29	1.46
Passenger in adjacent seat	BL	-	-	-
Passenger in adjacent seat	SCE	-	-	-
Reaching for food- or drink-related object	BL	0.65	0.14	2.91
Reaching for food- or drink-related object	SCE	1.73	0.48	6.27
Reading	BL	-	-	-
Reading	SCE	-	-	-
Removing/adjusting clothing	BL	0.44	0.05	3.74
Removing/adjusting clothing	SCE	0.26	0.08	0.83
Tobacco use	BL	-	-	-
Tobacco use	SCE	0.97	0.11	8.85
Talking/singing	BL	0.89	0.39	2.04
Talking/singing	SCE	1.28	0.59	2.79
Smoking-related: Cigarette in hand or mouth	BL	0.41	0.14	1.26
Smoking-related: Cigarette in hand or mouth	SCE	1.19	0.22	6.56
Reaching for object, other	BL	0.44	0.05	3.53
Reaching for object, other	SCE	0.61	0.29	1.30

Table 38. PERCLOS 1 fatigue OR and 95% CI in truck SCEs and BLs with specific cell-phone-related secondary task involvement.

Secondary Task	Event Type	OR	95% LCL	95% UCL
Cell phone: Hand-held browsing	BL	-	-	-
Cell phone: Hand-held browsing	SCE	3.09	0.58	16.56
Cell phone: Hand-held dialing	BL	-	-	-
Cell phone: Hand-held dialing	SCE	-	-	-
Cell phone: Holding	BL	-	-	-
Cell phone: Holding	SCE	-	-	-
Cell phone: Locate/reach/answer	BL	-	-	-
Cell phone: Locate/reach/answer	SCE	-	-	-
Cell phone: Hand-held talking/listening	BL	-	-	-
Cell phone: Hand-held talking/listening	SCE	-	-	-
Cell phone: Hand-held texting	BL	-	-	-
Cell phone: Hand-held texting	SCE	-	-	-
Cell phone: Hands-free call via headset/earpiece	BL	1.77	0.41	7.75
Cell phone: Hands-free call via headset/earpiece	SCE	2.34	0.29	18.83
Cell phone: Hands-free call via speaker phone	BL	-	-	-
Cell phone: Hands-free call via speaker phone	SCE	-	-	-
Cell phone: Hands-free talking/listening	BL	1.81	0.41	7.89
Cell phone: Hands-free talking/listening	SCE	2.38	0.30	19.12

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