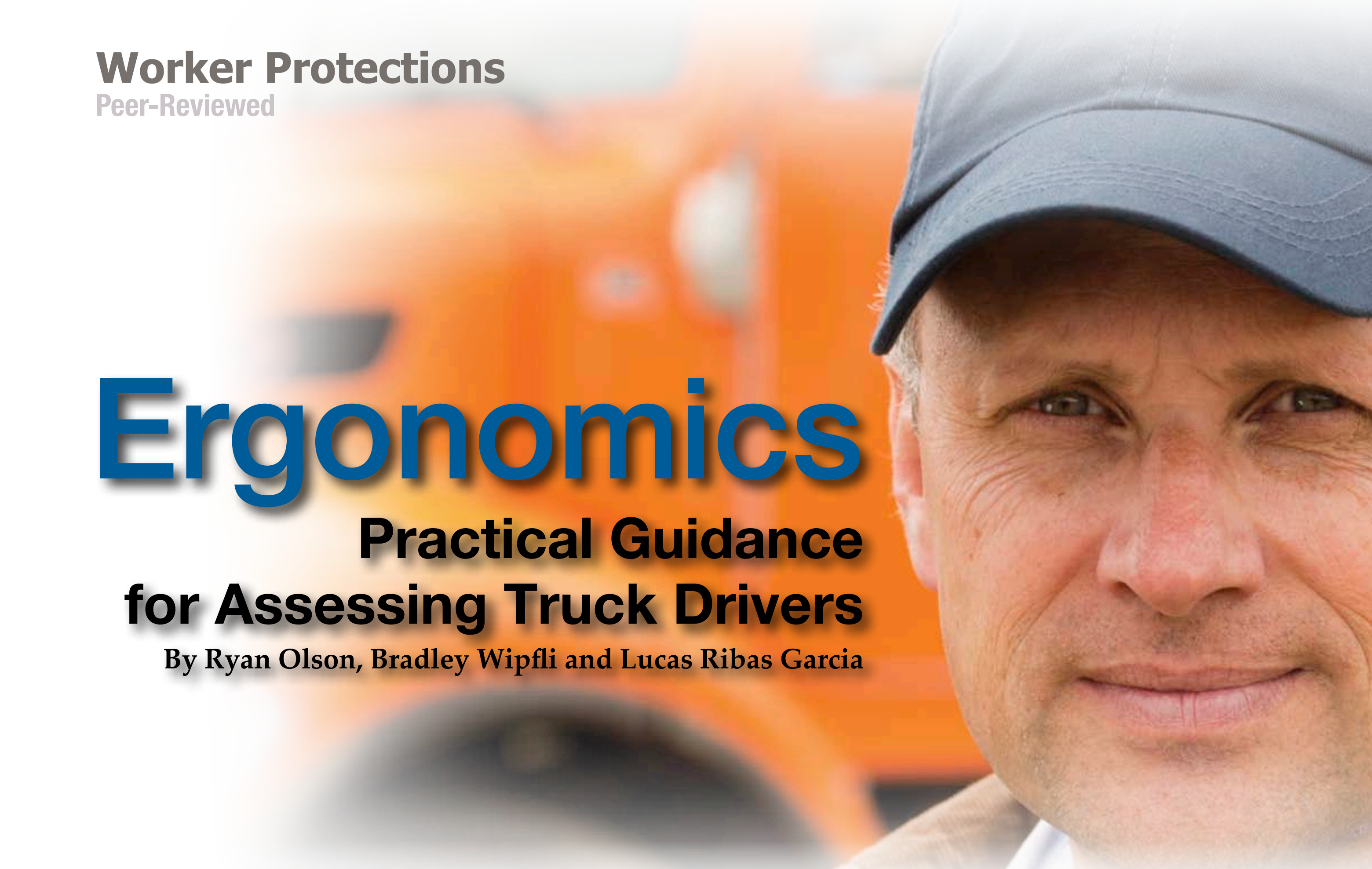

# Ergonomics

## Practical Guidance for Assessing Truck Drivers

By Ryan Olson, Bradley Wipfli and Lucas Ribas Garcia

**IN BRIEF**
- **Short-haul truck drivers perform frequent material handling tasks and have elevated levels of musculoskeletal disorders. However, conducting observational ergonomic assessments with truck drivers is particularly time consuming, and few practical guidelines discuss the number of observations required to generate accurate data.**
- **This secondary analysis assessed data gathered on three drivers as they performed material handling tasks during pickup/delivery stops.**
- **Given the effort required to obtain reliable observational measures of exposures among short-haul truck drivers, other forms of data collection should be used to supplement direct assessment of ergonomic hazards.**

Commercial truck drivers experience approximately 8% of all work-related musculoskeletal disorders (MSDs) in the U.S. and report an above-average number of lost workdays per injury (BLS, 2007). Prevalence rates for low back pain among truck drivers range between 50% and 81% (Miyamoto, Shirai, Gembun, et al., 2000; Robb & Mansfield, 2007), and truck drivers report experiencing low back pain intensity that is higher than any other occupational driving group (Okunribido, Magnusson & Pope, 2008).

Contributing factors to MSDs and low back pain among drivers include exposures to whole body vibration, prolonged sitting and material handling tasks. Material handling exposures are highest among short-haul truck drivers [also known as less-than-truckload (LTL) drivers] who typically deliver freight to customers within a single metropolitan area (Burks, Belzer, Kwan, et al., 2010). These drivers make multiple stops each day, and use their hands, hand trucks, pallet jacks and forklifts to load and unload freight. The physical demands on a short-haul route are affected by factors such as the freight being hauled, trailer technologies and customer environments. Little is known about how often drivers should be observed to obtain reliable measures of ergonomic exposures. The current study was designed to address this knowledge gap.

Observational ergonomic assessments help evaluate workers' exposures to injury hazards such as the frequency or duration of severe or awkward body postures. A fundamental issue in conducting such assessments is deciding how many observations are required to obtain reliable exposure data. To provide guidance on this topic, some researchers have conducted secondary analyses of relatively large observational data sets and estimated confidence intervals (CI) for exposure means for a range of different observational sampling strategies.

The CI approach is based on a basic principle of the central limit theorem—that random sample means drawn from a population will cluster more tightly around the true population mean (the standard error of the mean will reduce) as sample size increases (Fischer, 2010). Although no empirical or traditional criteria exist for deciding when an observational strategy has produced an acceptably narrow CI width for an exposure mean, visual inspection of plotted CI widths or arbitrary empirical cutoff points can be used to decide when additional

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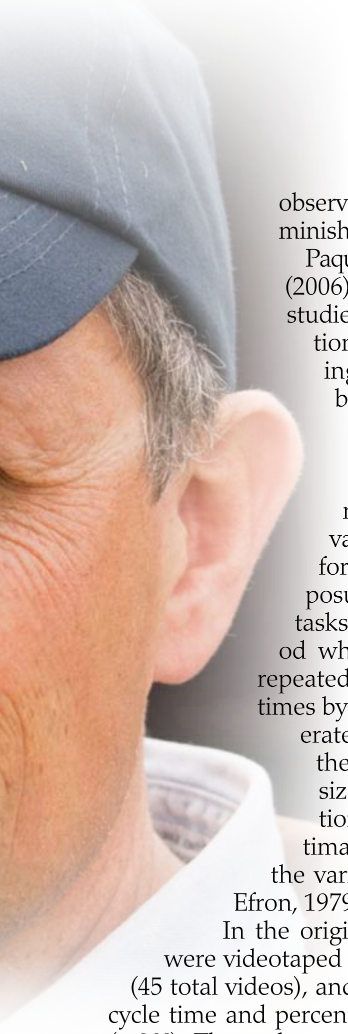


observations seem to produce diminishing returns in data accuracy.

Paquet, Mathiassen and Dempsey (2006) conducted two relevant studies to recommend observational sample sizes for measuring ergonomic exposures for both highly repetitive and more variable types of work. They used statistical bootstrapping to estimate the reliability of several observational sampling strategies for measuring ergonomic exposures during manufacturing tasks. [Bootstrapping is a method where an original data set is repeatedly resampled thousands of times by a software program to generate a sampling distribution of the mean for a given sample size. These sampling distributions can then be used to estimate confidence intervals for the variable mean of interest (e.g., Efron, 1979; Efron & Tibshirani, 1986).] In the original data set, three workers were videotaped three times a day for 5 days (45 total videos), and researchers measured task cycle time and percent time in mild trunk flexion (≥ 20º). The authors compared the CI width for a single observation to CI widths for three different observational strategies.

Based on visual inspection of CIs, the authors concluded that three observations were superior to one observation, but that it was best to space those observations over multiple days regardless of whether one or three workers were observed.

In another study, Paquet, Punnett, Woskie, et al. (2005), used similar statistical techniques to estimate the number of observations required to reliably measure ergonomic exposures during highway construction work, which is less routine and repetitive than manufacturing. Work groups from three construction operations were observed every 45 to 60 s over 10 to 15 days. CIs for exposures means were generated for 1 to 10 days of observation for nine ergonomic measures. Based on visual inspection, the researchers reported that the measure with the highest between-day variability (kneeling, squatting or leg bending during manual excavation) showed dramatic improvements in reliability during the first 5 observation days (CIs reduced from ± 30% to ± 15% time spent in that position/task) with diminishing returns thereafter.

For a measure with moderate variability (trunk flexion during ground-level rebar construction), the authors reported robust reliability improvements up to the 6th observation day (CIs reduced from ± 15% to ± 8%). For a very low variability measure (manual material handling during pit-wall construction), there was almost no advantage to observing workers for more than 1 day because CI widths only reduced from ± 4% to ± 2% by the 7th day.

Practical observation guidelines for measuring exposures with manufacturing or construction workers may or may not generalize to short-haul truck drivers. The primary material handling tasks performed by drivers are more variable than typical manufacturing tasks because loading and unloading occurs in a range of customer environments, and drivers handle freight that varies in weight, size, shape and packaging each day. In this regard, short-haul trucking is more similar to construction where tasks and environments vary.

Given these considerations, drivers probably should be observed more intensively than manufacturing workers (> 3 times) and possibly as intensively as construction workers (5 to 6 days). However, the authors know of no prior study with truck drivers that estimated the reliability of different observational sampling strategies for measuring ergonomic exposures during material handling tasks.

In most published ergonomic assessment studies involving short-haul truck drivers, observation periods have ranged from 0.5 to 2 days per driver (Hedberg, 1985; Miyamoto, et al., 2000; Nygård & Ilmarinen, 1990; Okunribido, et al., 2008; van der Beek & Frings-Dresen, 1995; van der Beek, van Gaalen & Frings-Dresen, 1992). However, Olson, Hahn and Buckert (2009) conducted a video-based ergonomic assessment study with short-haul truck drivers that included video observations of more than 700 pickup and delivery stops, which is sufficiently large to support a study of the reliability of observational sampling strategies.

The current project is a secondary analysis of the original Olson, et al. (2009), data set, and was designed to empirically estimate the number of observations required to reliably measure short-haul truck drivers' exposures to severe trunk postures and associated hazards. Results also may be relevant to conducting ergonomic assessment with other groups of lone workers who perform physically demanding tasks at multiple locations during a day, such as home care workers, mobile service and repair technicians, or house cleaners.

## Method

### *The Original Data Set*

In the original project (Olson, et al., 2009), three short-haul truck drivers were studied as they worked in a trailer fitted with a camera system that recorded their work during each pickup or delivery stop (total stops $N = 711$). Researchers used a reliable video-scoring system to measure the occurrence of various work exposures including occurrence of severe trunk postures during material handling tasks.

Severe trunk postures were defined as forward or lateral flexion of the trunk ≥ 45º (bent) and/or rotation of the shoulders ≥ 45º relative to the hips in the coronal plane (twisted) during material handling tasks. Regression analyses identified four significant predictors of severe trunk postures. For every one-unit increase in manual material handling, the predicted mean for severe trunk postures increased 7%. For every one-unit increase in the

Table 1 presents descriptive statistics for the five exposure measures based on the full data set.

**Table 1**

## Exposure Measures

| Variable | Driver 1 (n = 186) | 2 (n = 223) | 3 (n = 302) | All (N = 711) |
|---|---|---|---|---|
| Regular pallet | 1.35 (1.56) | 1.25 (1.50) | 1.03 (1.21) | 1.18 (1.41) |
| Nonstandard pallet | 0.45 (0.92) | 0.50 (1.22) | 0.69 (1.01) | 0.57 (1.06) |
| Forklift assistance | 1.09 (1.46) | 1.27 (1.90) | 0.93 (1.29) | 1.08 (1.55) |
| Manual material handling | 1.26 (3.00) | 1.54 (4.01) | 1.59 (4.51) | 1.49 (4.00) |
| Severe posture w/load | 0.89 (3.16) | 1.23 (3.17) | 1.21 (3.11) | 1.13 (3.14) |

***Note.*** *Mean counts and* SD *per stop for each dependent variable based on the full data set from Olson, Hahn and Buckert (2009).*
N *or* n *= number of stops observed. Data cell contents = Mean (*SD*).*

use of standard pallets, nonstandard pallets and forklift assistance, the predicted means for severe trunk postures reduced 20%, 22% and 12%, respectively.

### *Secondary Data Analysis: Selecting the Appropriate Levels of Analysis*

The current project was developed to estimate CI widths across a range of observational sample sizes for each variable in the Olson, et al. (2009), regression model. Before initiating observational CI estimation, several preparatory analyses were conducted to select the most appropriate levels of analysis for the data set.

The most practical way for an ergonomist to observe a short-haul truck driver would be to ride along for all or part of a workshift and measure exposures during each stop. Given the job's mobile nature, observers also would need to end assessments at a convenient location so drivers would not have to leave their routes to make an "observer drop." Therefore, for the current project, the research team set the observational unit of analysis as a half day so observations could conceptually end or begin at lunchtime. In the original study, drivers averaged about eight stops per half day.

In short-haul trucking operations, route differences could generate heterogeneity in ergonomic exposures across drivers. Therefore, the research team conducted tests to decide whether to pool or separate data at different levels for three variables: driver (driver 1, driver 2, driver 3); time of day (a.m. vs. p.m.) and day of the week (Monday through Friday). Since observational sample sizes were different for each driver, the team evaluated homogeneity of variance for each variable with a Levene's test, then computed Brown-Forsythe *F* ratios for variables with unequal variances when applicable. ANOVA results revealed between-driver differences in exposures for four of the five dependent measures, which suggests that observational CI estimates should be constructed separately for each driver.

Next, the team tested for differences in dependent measures across morning and afternoon stops within each driver using *t*-tests. Out of 15 possible comparisons (five tests across three drivers), only one was significant (driver 3, more forklift assistance in afternoon), which suggests that exposures were mostly homogeneous across time of day.

Finally, exposure levels across days of the week were evaluated by computing an omnibus ANOVA test for each driver with day of the week as the independent variable and ergonomic exposures as dependent variables (five tests across three drivers). Only one driver had significant differences in exposures across days of the week (driver 3, standard and nonstandard pallets), which suggests that exposures were also mostly homogeneous across days of the week.

In sum, preparatory analyses showed that although exposures differed across drivers, they did not differ much across time of day or day of the week within drivers. This suggests that observational CI estimates be constructed separately for each driver but without consideration for time of day or day of week. Since the nature of the data did not recommend testing more complex sampling strategies through statistical bootstrapping methods (e.g., balanced random selection of both a.m. and p.m. stops), formulaic computations were used to construct CIs for increasing observational sample sizes for each driver.

Photo 1: Trailers parked for loading at Peninsula Truck Lines, Portland, OR.

### *Confidence Interval Estimation & Empirical Criteria for Practical Recommendations*

Ninety-five percent CIs for exposure means were constructed for each observation interval using the formula for the standard error of the mean (*SD* divided by the square root of the subsample size) and the *z* score cutoff value of ± 1.96 standard error units for identifying upper and lower CI limits. In calculations, *SD* in the numerator was based on all available observations for each driver. Subsample sizes in the denominator were based on increasing half-day observation units (eight stops each) up to 11 half-day observation units (88 stops).

To evaluate the level of reduction in measurement error with each additional observational unit, researchers calculated the percent reduction in CI width at each interval relative to the original CI width for a single half-day observation. Two criteria were selected as the basis for conclusions about observation utility and reliability: 1) the number of observation units after which subsequent observation units produced limited (≤ 5%) reductions in mean estimation error (CI width); and 2) the number of observation units required to eliminate zero from CIs (95% probability of correctly concluding that the mean exposure for a variable was not 0).

**Results**

Table 1 presents descriptive statistics for the five exposure measures based on the full data set (Olson, et al., 2009). The average exposure count per stop across all five variables ranged from 0.45 to 1.59. Severe trunk postures and manual material handling displayed the most variability (*SD* range = 3.00 to 4.50), which suggested in advance that these measures would require the most observation units to achieve a reliable level of mean estimation.

*Confidence Interval Analyses*

After a single half-day observation, CI widths (upper limit minus the lower limit) ranged from 1.28 (driver 1, nonstandard pallet) to 6.24 (driver 3, severe trunk postures). After 11 half-day observations, the CI widths for these same two variables reduced to 0.38 and 1.42, respectively. As expected, the variables with the largest initial CI widths (severe trunk postures and manual material handling) also showed the greatest reductions in absolute units of CI width across the first several observation units.

However, in relative CI width units, all variables reached the preestablished criterion for diminishing returns after the 4th half-day observation, which means that relative to the original CI width for each variable, subsequent observations after the 4th half day produced percent reductions in CI width of ≤ 5%. The number of days required to eliminate 0 from the CIs for all dependent variables for a given driver ranged from 4 to 7 half days. The variable severe trunk postures required the most half-day observations before 0 was

Photo 2: A view from one of three camera angles from the Olson, et al. (2009), study.

**Figure 1**

## Driver 1: CI Widths

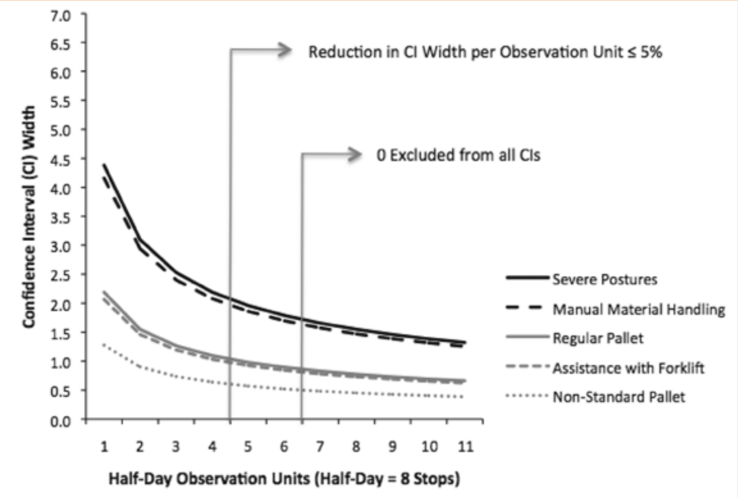
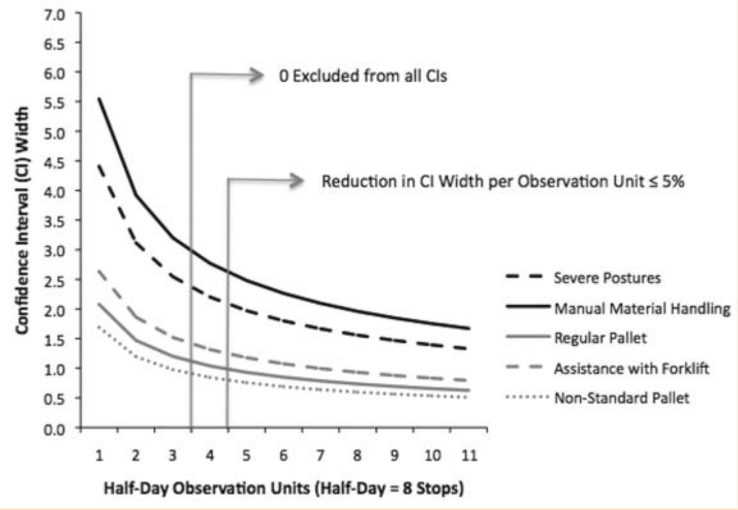



**Figure 2**

## Driver 2: CI Widths




Figures 1 and 2 show plots of CI widths for each dependent measure across increasing half-day observation units for drivers 1 and 2.

## Figure 3
# Driver 3: CI Widths

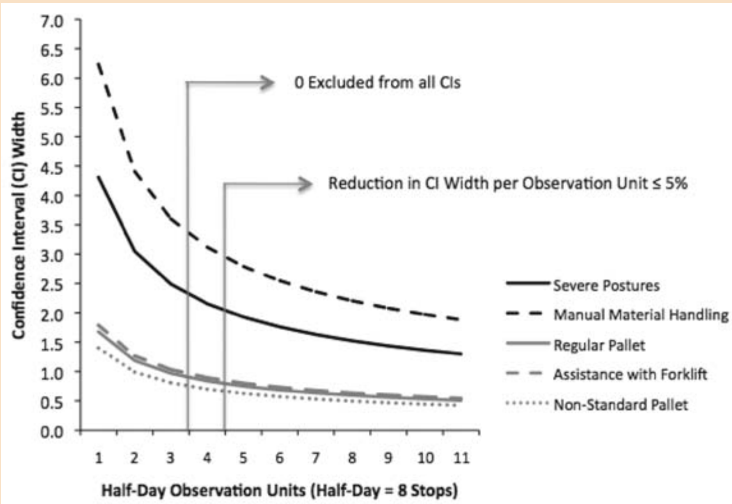



Figure 3 shows a plot of CI widths for each dependent measure across increasing half-day observation units for driver 3.

eliminated from CIs for all three drivers. For the variable regular pallet, 0 was excluded after a single half day of observation.

Figures 1, 2 (p. 41) and 3 show plots of CI widths for each dependent measure across increasing half-day observation units for drivers 1, 2 and 3, respectively. Vertical lines on the figures mark the points after which subsequent observations would produce diminishing returns and eliminate 0 from all CIs. Figure 4 shows the observation units required for each driver to eliminate 0 from the CI for each exposure.

## Figure 4
# Driver Comparisons for Half-Day Observations

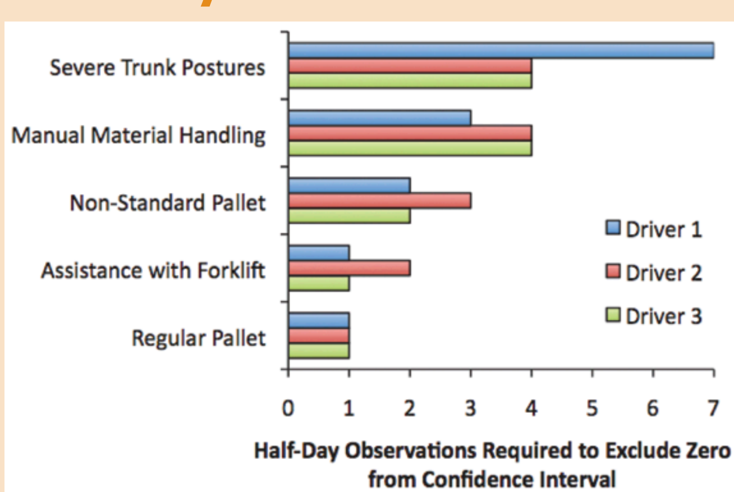



Figure 4 shows the observation units required for each driver to eliminate 0 from the CI for each exposure.

### Discussion

The current project was designed to identify the number of observations required to obtain reliable measures of ergonomic exposures among short-haul truck drivers. After 4 half-day observations (32 stops), subsequent observations produced limited reductions in relative CI width (≤ 5%). However, up to 7 half-day observations were required to eliminate 0 from the CI for severe trunk postures, which was the most variable measure in the study.

In contrast, only 1 half day was needed to eliminate 0 from CIs for regular pallet, which was the least variable measure in the study. Given these findings, more than 4 half-day observations would only be recommended for measuring exposures that are highly variable, which in the current study were factors with an *SD* of 3 or more counts per stop.

In the current study, statistically significant differences in exposures were observed across drivers; therefore, subsequent observational CI estimates were focused on individual driver routes. In this regard, recommendations based on the current study are limited to obtaining reliable measures of exposures for single driver's routes. However, the three drivers who participated in the original project may not have been representative of the 40 or more drivers who were employed by the organization at the time of the study.

This limitation raises practical issues for conducting ergonomic assessments in short-haul trucking organizations. It would be highly inefficient and time consuming to conduct 4 to 7 half-day observations with every driver. More feasible approaches would be to randomly select several drivers for observation, or to select specific drivers with potentially high exposure levels for observation.

### Practical Recommendations for Safety Professionals

Given the time-consuming nature of observing short-haul truck drivers, it may be advisable to supplement observations with other exposure measurement methods.

For example, drivers can accurately self-assess certain easy-to-discriminate variables, such as the presence of forklift assistance at customer sites. In Olson, et al. (2009), drivers' self-monitored data on many exposures for several weeks and drivers' measures of forklift assistance were highly correlated with objective researcher data collected from video recordings ($r = .85$, $p < .01$).

However, drivers were much less accurate at self-recording variables such as severe trunk postures ($r = .43$, $p < .01$). These data suggest that drivers or customers could be surveyed to gather data on exposures that are easy to track, such as forklift assistance or presence of a loading dock; these surveys could then be supplemented with observational assessments of exposures that are more difficult to self-assess, such as body postures.

The results of ergonomic assessments with truck drivers may suggest several types of interventions to reduce worker exposures. For example, if a safety professional discovers that customer sites without a loading dock are not evenly distributed among drivers, routes could be redesigned so that the burden of these demanding stops is distributed across the workforce. If a high number of customers are not providing forklift assistance (a predictor of severe body postures for drivers), an organization could charge an additional fee to those customers or provide a discount to customers who provide forklift assistance.

Other findings might suggest improvements in the way materials are loaded into truck trailers. For example, if drivers are found to be frequently manually handling nonpalletized or unsecured material, dock workers could experiment with ways to package or secure these materials so that drivers could move them with a hand truck or pallet jack.

#### Potential Relevance to Other Working Populations

The results of the current project are directly relevant to the specialized area of ergonomic assessment for short-haul truck drivers. However, it is possible that these recommendations could generalize to other groups of lone workers who perform physically demanding work at multiple sites each day.

For example, home care workers help the elderly and disabled with housekeeping and activities of daily living. Like short-haul truck drivers, these workers may visit multiple sites (client homes) each day and perform variable physical tasks, such as moving furniture while cleaning or transferring clients in and out of bed. Various jobs share some of these characteristics and present similar challenges for ergonomic assessment work, such as mobile service and repair technicians. In the future, researchers and practitioners should evaluate the degree to which recommendations for ergonomic assessment of truck drivers generalize to other groups of lone workers.

#### Conclusion

Short-haul truck drivers have elevated levels of musculoskeletal injuries and are a priority population for intervention. However, previous observational research with drivers has provided little practical guidance about the number of observations required to obtain reliable estimates of exposure means.

To address this knowledge gap, the authors conducted a secondary analysis of a large data set from a video-based ergonomic observation study of short-haul drivers (Olson, et al., 2009). CIs were computed for five important ergonomic exposure variables across 11 total half-day observations. Results suggest that there are diminishing returns in data accuracy after 4 half-day observations for all variables, but that up to 7 half-day observations may be required to reliably assess exposures to more variable factors in the study such as severe trunk postures. Given the effort and time required to observe short-haul drivers, it is recommended that practitioners supplement observational assessment with nonobservational data gathered from drivers or customers. **PS**

#### References


**Bureau of Labor Statistics.** (2007). Nonfatal occupational injuries and illnesses requiring days away from work, 2007. Washington, DC: U.S. Department of Labor, Author. Retrieved from **www.bls.gov/iif/osh_nwrl.htm#cases**.

**Burks, S.V., Belzer, M., Kwan, Q., et al.** (2010). Trucking 101: An industry primer (Transportation Research Circular E-C146). Washington, DC: Transportation Research Board.

**Efron, B.** (1979). Bootstrap methods: Another look at the jackknife. *The Annals of Statistics*, *7*(1), 1-26.

**Efron, B. & Tibshirani, R.** (1986). Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. *Statistical Science*, *1*, 54-77.

**Fischer, H.** (2010). *A history of the central limit theorem: From classical to modern probability theory*. New York, NY: Springer.

**Hedberg, G.E.** (1985). Physical strain in Swedish lorry drivers engaged in the distribution of goods. *Journal of Human Ergology*, *14*, 33-40.

**Miyamoto, M., Shirai, Y., Gembun, Y., et al.** (2000). An epidemiologic study of occupational low back pain in truck drivers. *Journal of Nippon Medical School*, *67*, 186-190.

**Nygård, C.H. & Ilmarinen, J.** (1990). Effects of changes in delivery of dairy products on physical strain of truck drivers. In C.M. Haslegrave (Ed.), *Work design in practice* (pp. 142-148). London, England: Taylor & Francis.

**Okunribido, O.O., Magnusson, M. & Pope, M.H.** (2008). The role of whole body vibration, posture and manual materials handling as risk factors for low back pain in occupational drivers. *Ergonomics*, *51*(3), 308-329.

**Olson, R., Hahn, D.I. & Buckert, A.** (2009). Predictors of severe trunk postures among short-haul truck drivers during nondriving tasks: An exploratory investigation involving video assessment and driver behavioral self-monitoring. *Ergonomics*, *52*(6), 707-722.

**Paquet, V., Mathiassen, S.E. & Dempsey, P.G.** (2006, Nov.). Video-based ergonomic job analysis: A practitioner's guide. *Professional Safety*, *51*(11), 27-35.

**Paquet, V., Punnett, L., Woskie, S., et al.** (2005). Reliable exposure assessment strategies for physical ergonomics stressors in construction and other nonroutinized work. *Ergonomics*, *48*(9), 1200-1219.

**Robb, M.J.M. & Mansfield, N.J.** (2007). Self-reported musculoskeletal problems amongst professional truck drivers. *Ergonomics*, *50*, 814-827.

**van der Beek, A.J. & Frings-Dresen, M.H.W.** (1995). Physical workload of lorry drivers: A comparison of four methods of transport. *Ergonomics*, *38*, 1508-1520.

**van der Beek, A.J., van Gaalen, L.C. & Frings-Dresen, M.H.** (1992). Working postures and activities of lorry drivers: A reliability study of on-site observation and recording on a pocket computer. *Applied Ergonomics*, *5*, 331-336.