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On the training and testing of entry-level commercial motor vehicle drivers

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ABSTRACT

This study examined the effectiveness of 3 different training types on commercial motor vehicle (CMV) drivers' skill levels. The training types included a conventional 8-week certified course, a conventional 8-week certified course with approximately 60% of driving time spent in a CMV driving simulator, and a Commercial Driver's License (CDL) test focused short course. Participants' scores on the Division of Motor Vehicles (DMV) road and range tests were assessed. In addition to their DMV scores, participants replicated DMV road and range driving tests in an instrumented vehicle and the CMV driving simulator. Results indicated no training group differences in DMV road tests. There were differences between training groups on DMV range tests and real truck and simulator versions of the DMV road and range tests; on these tests conventional- and simulator-trained participants generally scored higher than CDL-focused participants. However, all groups performed higher in the real truck than in the simulator for both road and range tests. These findings indicate the need for a minimum standard of entry-level CMV driver training as well as support of the use of a driving simulator for training entry-level drivers; however, testing using a simulator does not appear to be feasible with current technology.

1. Introduction

The recruitment of qualified commercial motor vehicle (CMV) drivers has been a perennial challenge for the commercial transportation industry. However, the licensing of CMV drivers has not always been subject to a unified standard. Prior to the United States Commercial Motor Vehicle Safety Act of 1986 there was not a nationwide Commercial Driver's License (CDL) testing and licensing program within the United States. This left each state free to set its CMV knowledge and skills requirements. Following the implementation of this legislation, CMV drivers were required to pass state Division of Motor Vehicles (DMV) tests administered to a Federally mandated minimum standard in order to obtain their CDL. However, as of 2010, there are no current requirements in the United States for minimum training levels for CMV drivers prior to licensure.

A variety of arrangements exist in other countries and regions. In Canada, CMV licensing standards are set by the provinces. For example, similar to the United States, Ontario requires CMV drivers to pass a written knowledge test and driving skills test prior to licensure (Ontario Ministry of Transportation, 2010). Quebec requires CMV drivers to either have 36 months of experience holding a passenger vehicle driver license, or 24 months of experience with a passenger vehicle driver license if the driver has completed vocational training for CMVs (Québec Automobile Insurance Corporation, 2010). The EU has set standards requiring all CMV drivers to undergo periodic training resulting in a certificate of professional competence (or CPC; ECE, 2003). The Australia Capital Territory (ACT) requires novice CMV drivers to pass knowledge and skills-demonstration tests prior to licensure (ACT Road Transport Authority, 2010). In contrast, New South Wales, Australia, requires novice CMV drivers to complete mandatory training prior to licensure (New South Wales Roads and Traffic Authority, 2010). New Zealand requires novice CMV drivers to move through different tiers, or classes, of licenses in order to move from medium rigid vehicles to heavy articulated vehicles (New Zealand Transport Agency, 2010). Drivers must spend at least 6 months in each successive license class before moving to the next higher class, or they may complete an approved training course to advance to the next class.

Outside of licensing issues, there is evidence that many CMV drivers are not adequately trained prior to licensure. After examining three private industry CMV sectors, including heavy trucks, motorcoaches, and school buses, Dueker (1995) concluded that no CMV industry sector was providing sufficient training in terms of time and curriculum to CMV drivers. While this situation may have changed in the years between Dueker's report and the present work commencing, there has been little reported evidence of meaningful

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shifts in CMV driver training in the literature. For the heavy truck industry sector, only 22% of motor carriers that hired entry-level drivers provided formal training. A smaller proportion of carriers provided adequate training; Dueker concluded that only one in ten motor carriers could be expected to provide adequate entry-level training to their entry-level CMV drivers.

Further evidence of the need for entry-level CMV driver training is the number of carriers that operate driver finishing programs. These are in-house training programs that ensure a newly licensed CMV driver has the minimum level of skills needed to operate a CMV for the carrier. Stock (2001) estimated that approximately 75% of motor carriers operate such programs. While CMV driver finishing programs provide for carrier-determined minimum skill levels, the variability in how the programs may be implemented, the lack of universal implementation of such programs within the commercial transportation industry, and the lack of standardized curricula in these programs make them an inadequate replacement for entry-level training. Unfortunately, there is little evidence on the effectiveness of CMV either novice or experienced driver training in the literature.

There are two broad forms of training a novice CMV driver may receive, and they differ in the absence or presence of a formalized curriculum. Training with no formalized curriculum is typically delivered by a friend, family member, or co-worker. Training situations and environments, as well as what knowledge and skills are introduced, vary widely in this informal training method. Relatively few drivers receive this informal training (Morgan et al., in press). In comparison to informal training, formalized curriculum training types may be further differentiated. One training type, herein termed conventional training, includes both classroom and behind-the-wheel (BTW) training and can meet criteria for independent certification (such as certification provided by the Professional Truck Driving Institute [PTDI], 1999). These conventional training programs are characterized by having a minimum number of classroom and driving training hours as well as limits on the student-to-instructor ratio. The other form of training with formalized curriculum is that provided by CDL-focused training programs. These programs are shorter in duration, typically lasting between 2 and 4 weeks, and provide the minimum level of knowledge and skills required to pass a state CDL exam. These programs are typically not eligible for independent certification and may widely vary in the student-to-instructor ratio.

In addition to conventional and CDL-focused training methods, simulation-based training has been viewed as a powerful method of training entry-level CMV drivers (Brock et al., 2001). Driving simulators, and especially CMV driving simulators, have a number of benefits that have been identified from their use in research and training. In either research or training settings, CMV driving simulators are tools that provide a replication of the driving experience in a manner that presents little possibility of harm to the driver-participant. There are several distinct advantages to simulator-based training for CMV drivers (Brock et al., 2007). Robin et al. (2005) summarized these benefits as:

- Providing for the safety of the driver and vehicle.
- Driving maneuvers that would be difficult and/or dangerous to reproduce (even on a skidpad) are relatively simple to produce in advanced training simulators.
- Drivers can be introduced to scenarios which are infrequent within the roadway environment or would be dangerous for a novice driver.
- Allowing for a higher level of standardization and repeatability in training curriculums.

In addition to the benefits identified by Robin et al. (2005), simulators offer the opportunity to obtain high quality measures of driver performance without increasing the level of risk that the driver experiences. Some situations, such as skidpads or emergency maneuver training, would be rare, difficult, or dangerous to replicate in BTW training. Simulation is a way to allow drivers to experience these scenarios in a safe and controllable environment.

Modern truck-driving simulators also increase the ability of instructors to develop and maintain training scenarios. Standardization in training scenarios, as well as standardization in exposure to events ensures that all trainees are exposed to the identical training exercises and scenarios. This is in contrast to BTW training, where variations in environmental conditions and wear of the truck's equipment can lead to different training exposure. In addition, while not available without specifically instrumenting a real vehicle, performance measurements are typically available in CMV simulators. This allows instructors to have quantifiable measures of driver performance and, in return, reduces the task load of the instructor with respect to observing all aspects of driver performance.

Efficiency is a critical issue for any training program. The efficiency of simulator-based training are one area that simulator-based training appears to holds an advantage over other forms of training (Brock et al., 2001). A factor in this higher efficiency is student throughput: whereas most CMV driving simulators require a low ratio of students per instructor, simulation also allows for the amount of time between students to be reduced (including reducing the amount of time training vehicles are out of service, lost training time due to weather conditions, etc.). The efficiency of a CMV simulator-based training program is also aided by the relative lack of service required for a simulator as compared to a real truck.

Simulation also may help engage, and subsequently increase training effectiveness for, trainee drivers. Engaging training scenarios offer a high degree of presence, which may aid training effectiveness. Defined as a subjective sense of being in one environment while being physically located in another (Witmer and Singer, 1998) or that the person using the simulation believes they are actually in the target of the simulated environment (Juang and Alessi, 2000), presence is connected with greater levels of performance and enhanced learning in simulator-based training (Witmer and Singer, 1998). Presence in simulations is dependent on the responsiveness and emotional connection of the user to the simulated task (Riva and Gamberlini, 2000). CMV simulators and scenarios that create a sense of presence and connection for the driver are likely to be more effective as compared to less immersive simulations and scenarios.

Simulator-based training is associated with some disadvantages. One of the greatest disadvantages to simulator-based training is that not all individuals are able to comfortably use driving simulators. This is due to a cluster of symptoms known as "simulator sickness" (Kennedy et al., 1993). Simulator sickness symptoms typically manifest as retinal image slip, nausea, and disorientation (Pausch et al., 1992). The simulation cues that result in simulator sickness are typically subtle; therefore simulation designers may not detect simulator sickness inducing cues during development. Some efforts have been made towards predicting individuals' susceptibility to simulator sickness: the Motion History Questionnaire (MHQ; Kennedy et al., 1992) attempts to predict simulator sickness from an individual's prior experiences with different motion types (e.g., boats, planes, amusement rides). Recent work has indicated the frequency of nausea experienced with different motion types throughout life may increase the predictive power of this approach (Golding, 2006). There are also means of quantifying simulator sickness symptoms. The Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993) consists of a 26-item symptom checklist and provides a quantification of symptoms along three factors (nausea, oculomotor discomfort, and disorientation) and an overall simulator sickness score. The refinement of simulator

Table 1
Participant demographics.

Training group	*n*	Participant gender	Mean age (years)	*SD* age
Conventional	33	31 male, 2 female	34	11.9
Simulator	32	31 male, 1 female	35	10.5
CDL-focused	33	30 male, 3 female	35	9.6

design, use of screening questionnaires, exposure measures should allow for a larger number of individuals to comfortably experience simulators.

Both training types and the duration of training vary widely among licensed CMV drivers. However, empirical examinations of CMV driver training and the resultant safety outcomes are complicated by the fact that a CMV driver's entry-level training method is not recorded in any large-scale databases. This, coupled with the continuing evolution of simulators, underscores the need for examining entry-level CMV driver training. The present study presents such an examination, with three distinctly trained groups of drivers evaluated in road and range driving performance.

2. Experimental method

2.1. Experimental design

Participants were grouped according to their entry-level CMV training type. The three groups included conventional (drivers trained in an 8-week, certified CMV driver training course at a community college with all driving occurring BTW), simulator (drivers trained in an 8-week, certified CMV driver training course at a community college where the majority of driving occurred in a CMV simulator), and CDL-focused (drivers who completed their entry-level CMV driver training at a short course designed to train the skills tested at DMV CDL examination locations).

Participants in the conventional and simulator groups were recruited during the first day of training in their 8-week community college CMV driving course. Participants in the CDL-focused group were recruited on the day of their CDL exam at the state DMV. All participants completed three different modalities of the same road and range tests (at the DMV, in a real truck [BTW], and in the simulator). The DMV road and range test scores were obtained from a DMV-maintained database. The BTW and simulator road and range test scores were scored by a PTDI-certified instructor, and the scores were validated by an independent reviewer to ensure scores were not biased against any group or test modality.

2.2. Experimental participants (drivers)

Ninety-eight individuals served as participants in the present study. All participants held valid automobile driver's licenses at the time of their participation, were medically qualified to operate a CMV under United States regulations, and had not previously held a full and unrestricted CDL (i.e., a CDL enabling them to drive heavy, articulated, vehicles with non-synchronized manual transmissions). Participants in the conventional and simulator groups, who were followed throughout their training cycle, were compensated for their time and participation with $400 USD while those participants in the CDL-focused group were compensated for their time and participation with $32 USD/h. A summary of participant demographics is provided in Table 1.

2.3. Experimental apparatus

2.3.1. Experimental venue and participant training

A Delaware (DE) community college offering an 8-week, PTDI-certified, entry-level CMV driver training program served as the experimental venue for conventional and simulator group training as well as the location for BTW and simulator testing for all participants. The experimental venue was chosen due to this state being one of the first to adopt revised CDL examination procedures that were being implemented across the country. This choice ensured all participants CDL examinations would occur under the same conditions.

Participants in the conventional training group received 50 h of BTW training in a heavy, articulated, tractor-trailer vehicle (time that included both road and range driving) and 147 h of classroom instruction (covering vehicle systems, theory of vehicle operations, log books, and U.S. Federal Regulations) during the 8-week course. Participants in the simulator training group experienced the same 147 h of classroom training as conventional training group participants. However, they received 42% of their driving practice in a real tractor-trailer and 58% in a CMV simulator. Each driving day for simulator participants included time in both the BTW and simulator environments. For both conventional and simulator training groups, these hours are actual training hours BTW of a truck or simulator only and do not include any observation time or time spent testing.

Participants in the CDL-focused training group received training at CDL-focused truck driver training schools. This type of training typically includes a compressed training schedule as compared to conventional training; CDL-focused participants reported receiving 4 weeks of training on average. Typical training of CDL-focused participants involved 3 days of classroom training (covering the CDL manual) and 17 days of BTW training. BTW training hours varied widely for participants (even within the same training cycle); however, most participants reported that most of their BTW time was spent on the range. On average, they reported a student-to-instructor ratio of 5:1.

2.3.2. Apparatus and measurement software

Four heavy, articulated, tractor-trailer vehicles were used for road and range BTW testing at the community college. These trucks use a 9- or 10-speed non-synchronized (double-clutching) manual transmission. A FAAC TT-2000-V7 driving simulator was used for simulator-based training and testing. This simulator provides a 225° forward field of view with five forward visual channels that use borderless screens. In addition, planar mirrors reflect images produced by two rear-mounted LCD screens, providing for simulated mirrors with parallax. A 3 degree-of-freedom motion seat and force-feedback steering provided additional feedback to the driver. The simulator was configured with a 9- or 10-speed non-synchronized manual transmission; the choice of transmission used in the simulator was matched to the actual vehicle the participant would be driving or testing with on that training day. Both the trucks and the simulator were instrumented with a data collection device allowing for video recording (at 10 Hz) of the driver, forward roadway, and left/right sides of the truck and trailer. This video was used to validate instructor scoring.

2.3.3. Training environment and scenarios

During the first 4 weeks of road training, participants drove a 9-speed double-clutching transmission with a 40-foot, empty van trailer. In the second 4 weeks of road training, participants drove both 9- and 10-speed double-clutching transmissions. Participants also drove both a half-loaded 45-foot flatbed and a half-loaded 48-foot van trailer. In addition to road driving, participants received 8 weeks of range driving consisting of a 9-speed double-clutching transmission with an empty 40-foot van trailer.

The simulator training group used scenarios created to replicate the conventional training group's daily lesson plans (including roadway environment factors such as road types and special road situations such as decreasing radius turns). The vehicle dynamics on the simulator (i.e., engine, transmission, trailer type) were changed depending on the corresponding conventional group's daily lesson plan. These routes, while parallel in structure, included features such as roadside wildlife (both stationary and moving), pedestrians (both stationary and moving), bicyclists and motorcycle riders, weather conditions, construction zones, weigh stations, crash scenes, and emergency equipment. In addition to the autonomous vehicles, programmed traffic events were added, including vehicles running a stop sign, unexpectedly backing out of driveways, pulling onto the roadway from the shoulder, and passing oncoming traffic in a direction facing the simulator driver.

CDL-focused participant training varied. However, most participants reported between 2 and 4 weeks of training. The first day of CDL-focused training was typically spent on hours-of-service reporting and log book keeping. On average, the rest of the training time was spent practicing road and range driving skills, with particular focus on the DMV-tested road and range driving maneuvers.

2.4. Driver performance assessment measures

Both the BTW and simulated range and road tests were developed to replicate the DE DMV road/range test. These tests included the same maneuvers as the DE DMV tests and were scored to the same criteria. A reviewer independent of the research team reviewed the scoring of both the BTW and simulated road and range tests using the video recordings of the tests; this review indicated that no systematic biases were present in the scoring of participants across the groups or across the test modalities (either BTW or simulator). As only the DMV test scores were available to the research team (i.e., the tests were not recorded or observed by the researchers), the DMV test scores were not able to be reviewed or validated.

The road test final score is based on performance in several aspects of road driving. These included aspects for turns (both left and right), intersections, different roadway conditions (expressways, urban, and rural roads), lane changes, curves, roadside pull-offs and re-entries, railroad crossings, traffic control device compliance, and general driving (including shifting). While driving on the road route, error points were accumulated by participants for mistakes in any of the scoring aspects. Serious errors, such as curb strikes or avoidable collisions, are considered automatic failures. Test administration, protocols, and scoring of DE DMV road testing (State of Delaware Division of Motor Vehicles, 2005) were also in effect for the BTW and simulator test modalities.

The range test final score includes performance on 6 backing or docking maneuvers: straight line backing, off-set (where the driver is required to back into an adjacent space) right, off-set left, 90° alley docking (where the driver is required to perform a 90° turn in the process of backing into a space), side sight parallel (a parallel parking maneuver performed for a space on the driver's left), and conventional parallel (a parallel parking maneuver performed for a space on the driver's right). Similar to the scoring of the road test, participants accumulated points for errors associated with each maneuver. It should be noted that DE DMV range testing only examines three of the six CDL backing maneuvers (straight line, off-set left OR right, and either a 90° alley dock, side sight parallel OR conventional parallel). The DE DMV randomly selects which maneuvers will be tested. However, the BTW and simulator test modalities examined all six CDL backing and docking maneuvers; thus the threshold for failing (i.e., accumulation of greater than 25 points) was double that of the DMV range test (i.e., accumulation of greater than 12.5 points).

Once a participant accumulated enough points to fail either the road or range test for any of the test modalities, that test was immediately stopped without assignment of a score. This is standard DE DMV test protocol and was also followed for the BTW and simulator test modalities. Table 2 displays the threshold for failing each of the test modalities.

Table 2
Failing score thresholds for each test modality.

Test modality	Points required for failure
Road tests	
DMV	>30
BTW	>30
Simulator	>30
Range tests	
DMV	>12.5
BTW	>25
Simulator	>25

If any participant accumulated enough points to fail a test or committed an automatic failure error, the test was halted as per DMV testing procedures. As participants were not allowed to continue testing once the failing threshold was met, it was unknown what their actual score would have been if they were allowed to continue. A score of 50 points was used for participants that failed the road test in an attempt to assign these participants a representative failing score.

2.5. Experimental procedure

Informed consent was obtained from all participants prior to participation. Following the informed consent process, participants in the conventional and simulator groups received full-curriculum, entry-level CMV driver training. As noted earlier, this training included 147 h of classroom training and 50 h of road and range driving training. For participants in the conventional group, this training occurred in an actual truck. For participants in the simulator group, 58% of driving training occurred in a simulator and 42% occurred in a BTW setting. For both conventional and simulator groups, driving training was performed with a 3:1 student-to-instructor ratio. The same road and range course curriculum was used in the BTW and simulator settings. Training (including both classroom and driving training) lasted a total of 8 weeks for these participants. At the conclusion of the 8-week program, both conventional and simulator group participants performed road and range tests in the DMV, BTW, and simulated settings.

The CDL-focused participants received training at a CDL-focused truck driver training school. The average duration of training these participants reported was 4 weeks and the training equipment participants reported using was similar to that used in training the conventional and simulator groups. The CDL-focused participants were recruited on the day of their scheduled CDL exam and thus were fully licensed as CMV drivers at the time of their participation in the study. After completing the DMV road and range tests, participants in this groups completed the BTW and simulator road and range tests.

3. Results

All data were screened for normalcy and violations of test assumptions prior to analysis. All analyses were conducted with SAS 9.2 for Windows, using a significance level set at $\alpha = .05$. Due to situations such as the DMV not reporting scores for a participant or participants not taking a simulator test due to simulator sickness (see Kennedy et al., 1993), some participants were excluded from individual analyses. Four conventional and 4 CDL-focused group participants did not take the simulator road or range tests (due to simulator sickness symptoms), and 2 simulator and 10 CDL-focused group participants' DMV road and range test scores were unavailable. These participants' data were excluded from all analyses presented in the present work. Thus, the results presented herein represent all complete data collected for the three groups.

3.1. Effect of training method on road test scores

Participants' final, total score on the state DMV, BTW, and simulator road tests were examined. In all cases the mean DMV road test scores were above 90%, regardless of group membership; no study participant failed the DMV road test. The lowest observed score was an 80 that was observed in the CDL-focused training group, and all training groups had occurrences of participants scoring perfectly. A greater amount of variability was present in the BTW and simulator road tests, with scores ranging from 50 (a failing score that occurred in all 3 training groups) to 97 (simulator training group). Fig. 1 displays the mean final road test scores for each group across all road test modalities.

A multivariate analysis of variance (MANOVA) was performed on the DMV, BTW, and simulator road tests. Using Wilks' criteria, the MANOVA was significant, $F(6, 148) = 27.15$, $p < .0001$. Therefore, follow-up analysis of variance (ANOVA) tests were performed in order to examine the effect of each training type on the individual DMV, BTW, and simulator test scores.

The ANOVA examining the effect of training type on DMV road test scores did not reach significance, $F(2, 78) = 1.70$, $p = 0.19$. Therefore, no further analyses were conducted on DMV road test scores.

An ANOVA examining the effect of training type on BTW road test scores was significant, $F(2, 78) = 109.39$, $p < 0.0001$. Tukey's test indicated that both the conventional ($M = 89.1$, $SD = 5.5$) and simulator ($M = 88.9$, $SD = 6.1$) training groups scored significantly higher than the CDL-focused group ($M = 55.6$, $SD = 12.3$) on the BTW road test ($p < .05$ in both cases).

An ANOVA examining the effect of training type on simulator road test scores was also significant, $F(2, 78) = 41.31$, $p < 0.0001$. Similar to the findings for the examination of BTW road tests, Tukey's test indicated that both the conventional ($M = 77.5$, $SD = 13.6$) and simulator ($M = 83.7$, $SD = 13.8$) training groups scored significantly higher than the CDL-focused group ($M = 51.1$, $SD = 5.8$) on the simulator road test ($p < .05$ in both cases).

3.2. Effect of training method on range test scores

The final, total score on participants' state DMV, BTW, and simulator range tests were examined in a similar fashion (provided, by test modality and group, in Fig. 2). Note that in all training groups

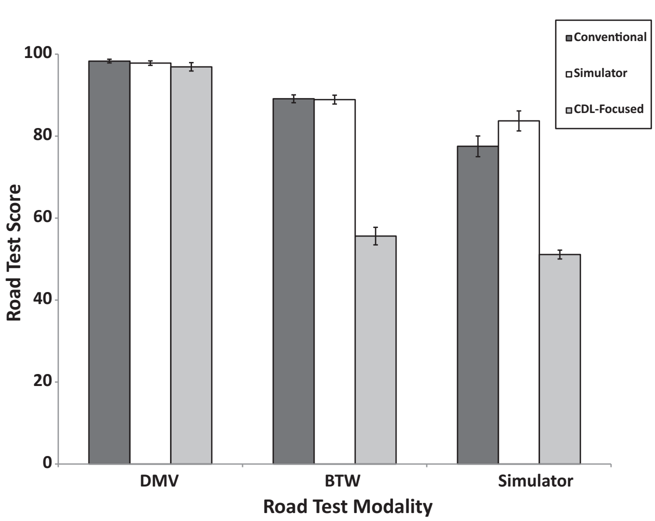

Fig. 1. Road test scores by modality.

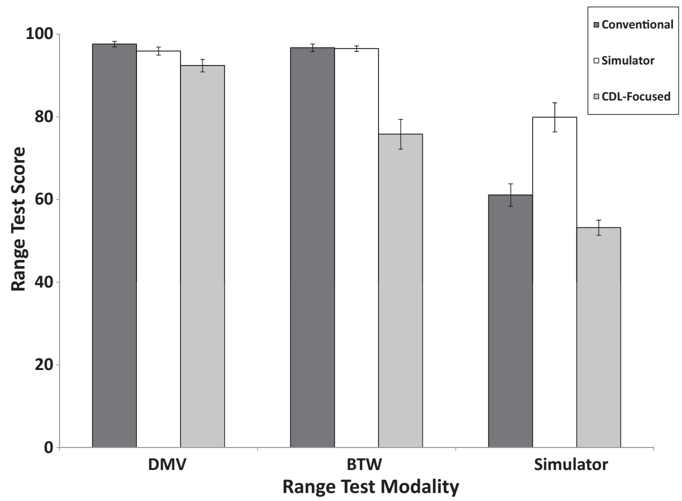

Fig. 2. Range test scores by modality.

the mean DMV range test scores were above 90%; no participant failed the DMV range test. The lowest score was a 76, observed in the CDL-focused training group; all training groups had occurrences of perfect scores (100). Analogous to the road tests, more variability was present in BTW and simulator tests. The scores for the BTW road tests ranged from a failing score of 50 (in the CDL-focused training group) to a perfect score of 100 (observed in all groups). Likewise, the simulator range tests varied from failing (occurring in all groups) to a perfect score of 100 observed in the simulator-trained group.

A MANOVA was conducted to search for group differences in DMV, BTW, and simulator range tests scores. Using Wilks' criteria, the MANOVA was significant, $F(6, 148) = 17.63$, $p < .0001$. Therefore, follow-up ANOVAs were conducted examining the effect of each training type on the DMV, BTW, and simulator test scores.

There was a significant main effect of the training group on the DMV range test score, $F(2, 78) = 6.45$, $p = 0.003$. Tukey's test indicated that the conventional training group ($M = 97.6$, $SD = 3.9$) had significantly higher scores on the DMV range test as compared to the CDL-focused training group ($M = 92.4$, $SD = 7.3$; $p < .05$). No other group comparison reached significance.

An ANOVA examining the effect of training type on BTW range test scores was also significant, $F(2, 78) = 37.34$, $p < 0.0001$. Tukey's test indicated that both the conventional ($M = 96.7$, $SD = 5.2$) and simulator ($M = 96.5$, $SD = 3.8$) training groups scored significantly higher than the CDL-focused group ($M = 75.8$, $SD = 20.7$) on the BTW range test ($p < .05$ in both cases).

There was also a main effect of the training type on simulator range test scores, $F(2, 78) = 20.12$, $p < 0.0001$. For the simulator range tests, Tukey's test indicated that the simulator training group ($M = 79.9$, $SD = 19.9$) scored significantly higher than either the conventional ($M = 61.1$, $SD = 14.6$) or CDL-focused ($M = 53.2$, $SD = 9.8$) training group ($p < .05$ in both cases). There were no significant differences between the conventional and CDL-focused groups' simulator range test scores.

3.3. Comparison of simulator and BTW testing

In order to assess if simulator-based testing was equivalent to traditional, BTW testing, final scores on the BTW and simulator road and range tests were compared. This comparison restricted test scores to those that were administered by the same personnel and independently validated; therefore, the DMV tests (that were administered by DMV personnel and were not able to be recorded or independently validated) were excluded from this analysis. The

Table 3
Comparison of BTW and simulator road and range test scores.

Training group	Comparison	*df*	*t*	*p*
Conventional	Road tests	28	5.11	<.0001
	Range tests	28	12.84	<.0001
Simulator	Road tests	32	2.14	.04
	Range tests	31	5.14	<.0001
CDL-focused	Road tests	28	2.51	.02
	Range tests	28	6.64	<.0001

BTW and simulator road test scores were compared for each training group using paired-sample *t*-tests. The results indicate that all groups' road scores significantly differed between BTW and simulator test modalities ($p < .05$ in all cases). For the conventional, simulator, and CDL-focused training groups, BTW road test scores were significantly greater than the simulator road test scores. Similar results were present for the comparison of BTW and simulator range test scores using paired-sample *t*-tests. The BTW and simulator range test scores differed significantly for all groups ($p < .0001$ in all cases), and in all cases, BTW range test scores were greater than the equivalent simulator range test scores. Table 3 provides the results of this analysis.

4. Discussion

The purpose of this study was twofold: to evaluate the relative benefits of different training methods and to evaluate the use of a CMV driving simulator for testing purposes. These are currently crucial topics due to constant demand for qualified CMV drivers. However, before any particular training method is recommended, analysis of the training method's effectiveness is warranted. Likewise, with simulators it is critical to examine the effectiveness of simulation-based training and testing prior to the widespread adoption of such training and testing methods.

The road test examined several aspects of the safe operation of a CMV on the road such as the ability to properly traverse turns, intersections, and encounter different road types. The analysis of the effect of training type outcomes of the various road test results indicate that there are important differences between conventional, simulator, and CDL-focused training methods in terms of CMV road driving skills. This is perhaps best illustrated by considering the differences in BTW road test scores, where the participants with longer training courses (the conventional- and simulator-trained groups) were observed to have significantly higher scores than participants in the CDL-focused courses with a much shorter duration. Likewise, the simulator road tests displayed a difference between those participants who had longer training courses (the conventional and simulator training group) and those who did not (the CDL-focused training groups). Further, for all groups (including the simulator training group), the simulator road test scores were significantly lower than those of the BTW road test scores. This suggests that the simulator road test is not able to accurately recreate the BTW road test conditions, although it does allow for adequate training of entry-level CMV drivers.

In contrast to the simulator and BTW road tests, the DMV road test displayed very little variability. In fact, no study participant failed the DMV road test. Average scores on the DMV road test for all groups were above 90%, and there were no significant differences in DMV road test scores between the three groups. This would suggest that the DMV road test differed in its administration or scoring from the BTW and simulator versions of the test. This was an unanticipated finding, as both the BTW and simulator road tests (as well as the respective range tests) were intentionally designed to replicate all tested aspects of the DMV test and were scored with the same criteria. Further, the BTW and simulator tests were independently and blindly scored by an external professional CMV driver training examiner, who found no bias or significant error in the test scoring. This would nominally suggest that the DMV road test is administered and scored to a more lenient criteria. Unfortunately, it was not possible to independently review the administration of the DMV road tests, preventing the researchers from being able to conclude with certainty the source of this finding.

The range test examined backing maneuvers with a heavy, articulated, combination (i.e., tractor-trailer) vehicle. These are maneuvers that CMV drivers commonly make in the process of a normal day such as backing to a loading dock. In contrast to the examination of road test scores, there were significant differences between groups on the DMV range tests. While no participant within any of the groups failed the DMV range test there was a significant difference between the conventional and CDL-focused trained participants. The participants with conventional training had higher scores on this test as compared to the CDL-focused participants; however, there was no difference between the conventional and simulator or the simulator and CDL-focused participants. This, coupled with the rather high average score and restricted range of scores observed in the DMV range test leads to the conclusion that this lack of differentiation may be due to similar factors as in the DMV road test (albeit, perhaps, to a lesser degree).

The BTW range tests provided similar findings to the investigation of BTW road tests. There were significant group differences in the BTW range tests, with the conventional and simulator groups being more likely to have a higher score than the CDL-focused group. This, again, seems to indicate that the longer training associated with both the conventional and simulator training groups lead to higher scores on the range test.

For the simulator range tests, the simulator group significantly outperformed both the conventional and CDL-focused groups. However, this result must be viewed in light of the fact that the simulator group's scores on the simulated range test were significantly lower than their scores on the BTW range test (a result found in the other two groups as well). Therefore, it is more likely that the simulator range test was not acting as a fair assessment of actual range maneuver skills when compared to the BTW range test.

There are some limitations of the present study that must be mentioned. First, the recruitment procedures used for the three groups may have resulted in participants self-selecting into either more formalized (8-week community college training) or less formalized (CDL-focused training) training programs. Therefore, there is the possibility of some a priori difference in participants prior to training. However, comparison of participants using the "Big Five" personality factor questionnaire (Goldberg, 1992; discussed in Morgan et al., in press) revealed no significant differences between the groups. Additionally, while attempts were made to standardize as many factors between the groups as possible, it was not possible to standardize the training equipment used by the CDL-focused group. While this group's familiarity, or lack thereof, with the equipment used for testing may have had an effect on their performance, all members of the CDL-focused group were licensed CMV drivers at the time of testing. The equipment the CDL-focused participants reported training with was similar to that used by the conventional and simulator groups (i.e., non-synchronized manual transmissions, at least 14.6 m long trailers, etc.). Therefore, the CDL-focused participants could reasonably be expected to have the skills needed to successfully operate a heavy vehicle.

Another factor that deserves mention is the perceptual and psychomotor differences between the study simulator and real vehicles. Although a worthy topic of discussion, there has been little published research on the perceptual differences (e.g., kinetic, focal, optic flow, etc.) between a real and simulated CMV and how these differences may affect training outcomes. The present study's design accommodated these potential differences and, regardless of their presence or absence, the results are the same. While outside of the scope of the present study's main research questions, future research examining the impact of these differences on the effectiveness of simulator-based training is warranted. Research on these potential differences will be of use to the simulation design and training community.

Overall, these findings indicate that training in a CMV driving simulator can result in drivers having skills equivalent to drivers trained in a conventional BTW manner and, in fact, the simulator group drivers had higher levels of performance on some tests as compared to CDL-focused trained drivers. However, simulator-based testing presents a much more complicated picture. While the simulator and CDL-focused groups had relatively equivalent performance between each group's respective BTW and simulator road tests, both had overall lower scores in the simulator range tests as compared to the BTW range tests. Further, the conventional group had lower scores in both simulator road and range tests. All three groups were observed to have lower scores in range tests conducted in the simulator versus the BTW environment. While some of the observed findings could possibly be attributed to test effects, as a whole, comprehensive simulator-based testing including both road and range testing does not appear to be feasible with current simulator technology.

5. Conclusion

Based on the findings of this study, increasing the amount of time an entry-level CMV driver trains offers advantages in terms of skill demonstration in the CDL road and range driving tests. Participants in this study who experienced the longer training consistently had higher levels of performance on the BTW tests as compared to the CDL-focused trained participants. This difference may lie in the fact that the conventional and simulator trained participants received classroom instruction about the theory behind heavy vehicle operations, whereas the CDL-focused trained participants typically received only classroom instruction about CDL exam topics. In addition, the longer exposure to driving a CMV in a controlled and supervised setting appears to have beneficial effects on drivers' abilities as measured on the CDL exams.

One of the more interesting findings of this study is the lack of differentiation in DMV road and range tests. In comparison to the BTW test that was independently validated, both DMV road and range tests did not appear to be sensitive to the skills they intend to assess. As stated earlier, it was not feasible to perform an independent validation of the DMV road and range tests, yet some explanations are possible. While clear testing standards are provided by organizations (such as the American Association of Motor Vehicle Administrators), the standards tests may not be adhered to in practice. Alternatively, the individuals administering the CDL exams for the DMV may not have the necessary knowledge regarding CMVs to adequately assess a driver's skills. Therefore, it may be beneficial in terms of efficiency and public safety to further examine how DMV CDL exams are conducted and scored.

Some of the largest factors driving the implementation and investigation of simulator-based training and testing for CMV drivers are the promise of reduced operational costs and the ability to have standardized and replicable testing conditions. However, these outcomes are dependent on simulator-based testing being a valid simulacrum of the actual vehicle. To be an effective replication of actual vehicles for training, a simulation must offer sufficient fidelity across many aspects (physical, environmental, visual; and see Young et al., 2008) in order to ensure adequate transfer of skills between the simulator and an actual vehicle. For testing purposes, the simulator must allow for skills to be demonstrated within the simulated environment in a manner allowing for both the CDL exam administrator and the administrating DMV to be certain that the skills being assessed will be present when the individual is operating an actual CMV. The assessment of comparable tests in three modalities (the DMV, BTW, and simulator environments) provides the ability to comment on the simulator's ability to provide such a transfer and assessment of skills.

The results of the present study indicate that drivers trained with the majority of their driving occurring in a simulator possess skills equivalent to those trained in an actual vehicle. Therefore, it may be concluded that the skills practiced within the CMV driving simulator are transitioning to the actual CMV driving environment. However, this must be underscored by the fact that only approximately 60% of total driving time was occurring in the simulated vehicle. Whether or not this percentage represents a ceiling cannot be determined with the current data, and additional research is needed to examine what limits actually bound the 60% result of this study.

Testing CMV drivers using a simulator presents different issues than training an entry-level driver. Universally within the present study, participants were not able to demonstrate the same level of performance in the simulated environment as they were able to demonstrate in the actual vehicle. It is somewhat surprising that the simulator-trained participants were not able to perform equally well between the simulator and BTW tests in either road or range driving. Several hypotheses present equally valid explanations for this finding; however, without a detailed examination of the psychophysical and perceptual factors that underlie the skills tested, conclusions are unable to be drawn on this matter. However, based on these findings, it can be concluded that simulator-based testing for CMV drivers is not feasible with current levels of simulator technology. Yet simulation is a rapidly evolving field; revisiting the issue of simulation-based testing after simulator technology has developed is certainly warranted.

Although this study was limited to an investigation of entry-level (that is, novice) CMV drivers, simulation-based training for experienced drivers deserves further empirical analysis. The CMV driving simulator used in the current study was able to provide adequate training to entry-level drivers. These drivers were being trained on the basic operational skills behind driving a large articulated vehicle. However, simulators are unique in their ability to provide experiences that would be either difficult or extremely dangerous to replicate in the real world. Using a CMV driving simulator to provide drivers with experiences of hazardous weather conditions, mechanical failures, and infrequent roadway hazards is entirely feasible with current levels of technology. Drivers may receive targeted training with the simulator following a safety violation or incident. Training for specific behaviors such as fuel economy is possible. Whether or not these skills rehearsed in the simulated environment would transfer to experienced drivers' everyday operational runs remains to be investigated.

Providing longer, more structured training for CMV drivers offers distinct benefits that may increase operational safety on public roads. Beyond this, simulators could potentially be used to replace some of the time normally spent training in an actual vehicle. If structured correctly, this could result in cost savings for an organization and allow for novice CMV drivers to be introduced to a heavy vehicle in a safe and controlled manner. Furthermore, simulators continue to rapidly develop in terms of their ability to provide a veridical representation of the physical and visual aspects of driving. This may ultimately extend their usefulness for driver training into the realm of driver testing.

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