Transportation Research Part C 58 (2015) 749–759

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Eco-driving training of professional bus drivers – Does it work?

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ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form 31 March 2015
Accepted 8 April 2015
Available online 22 April 2015

Keywords:
Bus drivers
Eco-driving
Training evaluation
Economical driving
Fuel economy
Simulator training

ABSTRACT

The drive to reduce fuel consumption and greenhouse gas emissions is one shared by both businesses and governments. Although many businesses in the European Union undertake interventions, such as driver training, there is relatively little research which has tested the efficacy of this approach and that which does exist has methodological limitations. One emerging technology employed to deliver eco-driving training is driver training using a simulator. The present study investigated whether bus drivers trained in eco-driving techniques were able to implement this learning in a simulator and whether this training would also transfer into the workplace. A total of 29 bus drivers attended an all-day eco-driving course and their driving was tested using a simulator both before and after the course. A further 18 bus drivers comprised the control group, and they attended first aid courses as well as completing the same simulator drives (before-after training). The bus drivers who were given the eco-driving training significantly improved fuel economy figures in the simulator, while there was no change in fuel economy for the control group. Actual fuel economy figures were also provided by the bus companies immediately before the training, immediately after the training and six months after the training. As expected there were no significant changes in fuel economy for the control group. However, fuel economy for the treatment group improved significantly immediately after the eco-driving training (11.6%) and this improvement was even larger six months after the training (16.9%). This study shows that simulator-based training in eco-driving techniques has the potential to significantly reduce fuel consumption and greenhouse gas emissions in the road transport sector.

1. Introduction

Around 11% of the greenhouse gases emitted each year come from within the European Union. In an attempt to reduce the EU's environmental impact the EU has committed to a 20% reduction in greenhouse gas emissions by 2020 (as compared with 1990). Although the EU and most of the member states appear on track to meet this commitment, transport is one area where reductions have not materialised. Overall, the transport sector account's for 20% of the greenhouse gas emissions produced by the 28 EU member states and data from 2011 shows that emissions from this sector have grown by 19% since 1990. In order to try and reduce greenhouse gas emissions from transport the EU has discussed and made several proposals regarding improving support for the use of alternative fuels, which will require substantial investment in infrastructure and the

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http://dx.doi.org/10.1016/j.trc.2015.04.010
0968-090X/

vehicle fleet. However, another more immediate, less costly and perhaps easier approach to reducing greenhouse gas emissions would be to train and motivate everybody to drive in a more fuel efficient manner.

Training individuals to drive in a more economical manner would be particularly important for professional drivers, who in general drive longer distances than the general public. A number of organisations have implemented driver training to improve fleet safety and fuel efficiency, but several researcher have questioned whether driver training is effective (e.g. Christie, 2001). However, a randomised controlled trial of four fleet safety interventions showed that there is at least the possibility that driver training could be effective if the right interventions are put in place, with the driver training group showing a significant reduction in crash costs (Gregersen et al., 1996).

There have also been a number of peer-reviewed studies investigating whether eco-driving training results in more economical driving amongst small and medium sized vehicle drivers (Andrieu and St Pierre, 2012; Beusen et al., 2009; Rutty et al., 2013), as well as buses (Carrese et al., 2013; Strömberg and Karlsson, 2013; Wahlberg, 2007; Zarkadoula et al., 2007) and trucks (e.g., Reed et al., 2012; Strayer and Drews, 2003), but all of these have methodological short comings which call into question their conclusions. The main methodological issues include: very small numbers, short monitoring periods, missing details, artificial driving conditions, self-selected participants and the absence of control groups.

Rutty et al. (2013), for instance, tested the effect of eco-driving training on 15 medium sized vehicles using in-vehicle data monitoring. They monitored vehicle performance on a number of variables (e.g., hard acceleration, idle time, CO_2 produced and fuel cost from idling) one month before and one month after the eco-driving training. They found that the training resulted in a daily reduction in idling time of between 4% and 10% and that average emissions of CO_2 were reduced by 1.7 kg per vehicle per day. However, there was no control group employed in this study so it is possible that something other than the training may have been responsible for the changes observed. It is also not clear whether any of these changes were statistically significant and the drivers were only monitored for one month, meaning that this study does not provide any information on long term behavioural changes. Furthermore, the drivers self-selected and were therefore most likely already interested in eco-driving; although it is not mentioned precisely what the participants were told before commencing the study.

Similar problems were also evident in another study testing the impact of eco-driving knowledge on car driving (Andrieu and St Pierre, 2012). Andrieu and St Pierre investigated whether simply providing advice on eco-driving was as effective for encouraging economical driving as attending an eco-driving course. They had two groups; the first group consisted of twenty drivers who drove a 14 km route "normally" in a manual Renault Clio before being given advice on the golden rules of eco-driving and then driving the same route again "economically". The authors state that these two conditions were counterbalanced, although it is difficult to understand how half drove economically before being given advice on the golden rules of eco-driving. The second group ($n = 19$) used an automatic Renault Megane and drove a 70 km journey twice, once normally and the second after the eco-driver training course. They found that fuel consumption was improved by 12.5% using simple advice on eco-driving and by 11.3% for the eco-driving training.

However, there are a number of issues with the comparisons made by Andrieu and St Pierre (2012). Firstly, there was no control group data reported and thus any changes could be due to something other than the training or advice. Moreover, the two vehicles were different as was the length of the route thus making any comparisons difficult. In addition, four members of the first group were also eco-driving instructors, who were presumably very skilled and knowledgeable about eco-driving and were probably also strongly motivated to demonstrate a substantial difference between normal and eco-driving. Furthermore, these cars were not their normal vehicles and were only used for the length of the trials. They also knew they were being monitored and were only monitored for a very short period of time over a test route. Unfortunately this study does not tell us whether those trained will use this advice and training when driving their own or company vehicles in normal everyday conditions and if so how long this behaviour will be maintained. Therefore, this research largely only demonstrates that, when monitored drivers appear able to put the training and advice into practice. A number of these problems were also evident in a study of Belgian car drivers (Beusen et al., 2009).

Beusen et al. (2009) investigated whether eco-driving training would lead to an improvement in car drivers' fuel economy. On-board logging devices were used to monitor 10 participants driving their normal car under every day conditions. Fuel economy data were collected during the period four months before and four months after the course. After the course their fuel economy was on average 5.8% better than before the course. These were individuals driving in real conditions in their own car, over an extended period of time, meaning this was a less artificial measure of the impact of eco-driving training. The improvement in fuel economy occurred immediately following the course and was maintained after four months. However, this was a within subject design without a control group, meaning that again some other external factor may have contributed or caused the observed change in fuel economy. Moreover, this was a self-selected sample, in that the participants were recruited using an advertisement for participants, so presumably they already had an interest in eco-driving (although it is not mentioned what the participants were told about the study). Further to this point, the authors state that some of the drivers were already clearly improving fuel economy figures before they had attended the course, indicating that at least some of the improvements in fuel economy were not due to the eco-driving training.

The research on truck driver training has similar problems. In one of the first studies to investigate the benefit of simulator-based training for reducing fuel consumption Strayer and Drews (2003) found an average improvement of 2.8% in fuel efficiency for the six months following simulator-based training. However, this research did not include a control group and it is not mentioned how the participants were selected. Also in 2003, a full mission truck driver training simulator (TruckSim) became operational at the Transport Research Laboratory in the UK. From 2003 to 2004 over 600 drivers took part in training and validation trials, but no transfer to real-road conditions was undertaken at this stage. Some years later, TRL reported an 11% improvement in fuel efficiency over three eco-training sessions. The biggest gains were made during the first training session with average RPM dropping by 22% and 29% fewer gear changes. A small-scale transfer of training study was also reported, which demonstrated a 7.3% improvement in fuel efficiency, but only six driver participated, there was no control group and no information about the follow-up time period (Reed et al., 2012).

There are also a small number of studies which have investigated the impact of eco-driving training on bus drivers. For instance, Zarkadoula et al. (2007) investigated whether eco-driving training would enable urban bus drivers to drive in a more economical fashion. In the pilot phase, which was one and a half months long, they measured the fuel consumption figures for three bus drivers. These bus drivers were then asked to drive a pre-selected 15 km route while their fuel economy and driving time were measured. Following this the three drivers attended an eco-driving seminar (the authors do not state the duration of the seminar) and they were again asked to drive a pre-determined 15 km route while their fuel consumption and driving time were measured. Two of the drivers made substantial fuel savings (up to 17.8%) which was not at the expense of time (3.04–8.11% faster), while the third driver consumed 1.78% more fuel and their travel time was increased by more than 40%. Zarkadoula et al. then investigated whether these practices would be used in everyday working conditions. They monitored two buses for two months and found a 4.35% reduction in fuel consumption per kilometre. However, this improvement was only for two buses and there was again no control group, meaning that some other factor, or simply monitoring the drivers could have caused this reduction. Furthermore, this reduction was only monitored for two months, meaning that the longer term effects of eco-driving knowledge are not known.

Strömberg and Karlsson (2013) investigated the impact of eco-driving training and in-vehicle feedback using three groups. In their study, the first group received in-vehicle feedback in real time, while the second group received this in-vehicle feedback and two personal training sessions. The third group was intended to be their control group. They tracked their fuel consumption before and after these interventions were put into place and reported an overall 6.8% reduction in fuel consumption (both groups combined). However, as there was again no control group information reported (due to participant drop out), it was not possible to determine whether these changes were caused by some factor other than these interventions.

In a more extensive study amongst bus drivers in their own working environment, Wahlberg (2007) investigated, amongst other things, the effects of training in fuel efficient driving by collecting fuel company figures for buses over several years. He found that the training did not transfer well into the drivers work environment, resulting in a fuel saving of approximately 2% one year after training. Although it is unclear, it appears that Wahlberg based this conclusion on data from 20 buses and that no comparison was made with a control group. It is also unclear what the bus drivers were told about the study aims and whether they were told their fuel consumption was being monitored.

The preceding research shows that the impact of eco-driving training has not been adequately evaluated in car or bus drivers. Part of the reason for the absence of this information is that it is very difficult to conduct this type of research in a field setting as there are many different problems to overcome, including: several people using the same bus so it is difficult to allocate fuel consumption to individual drivers, drivers may change routes which have different characteristics, the weather, routes may change, servicing of vehicles, traffic congestion, number of passengers, type of vehicle may change (e.g., as a response to a change in route), drivers may go on holiday and turnover of bus drivers. Nevertheless, if industry and governments are to invest time and money in this type of training it is essential that it is evaluated in a methodical manner.

The use of driving simulators, as an emerging technology for training professional drivers, has gathered momentum, since the European Commission Directive on Training for Professional Drivers (Directive 2003/59/EC) came into effect in September 2009. Amongst other things the Directive stipulates that lorry, bus and coach drivers must undergo a minimum of 35 h of training every five years. Furthermore, the directive offers scope for a proportion of this training to be conducted on a 'top of the range' driving simulator. There are a number of reasons why a driving simulator might be useful technology for training commercial drivers, including: the ability to provide a safe driving environment; to reproduce scenarios for standardised and repeatable training; to obtain high quality measures of driver performance; to reduce the amount of time training vehicles are out of service and reducing lost training time due to weather conditions (Robin et al., 2005). However, one of the main disadvantages in the use of this kind of technology for driver training is "simulator sickness", which is thought to be due to retinal image slip and may result in nausea and disorientation (Kennedy et al., 1993).

To date, very little published research has evaluated the benefit of simulator-based training for professional drivers and those which do exist have weak research designs. Of the few studies investigating the benefit of simulator-based driver training, some findings appear to show that negative transfer can occur (e.g., Uhr et al., 2003). Uhr et al. compared the effectiveness of driver training in a real vehicle with that of an advanced driving simulator. Experienced truck drivers were taught to reverse park a truck, with an attached trailer, from one side of the street to the other and, following this training, both groups attempted the manoeuver a further three times in a real truck. Both positive and negative transfer from the simulator was found, suggesting that simulator training was equivalent to behind the wheel training. However, the simulator-trained group took longer to complete the manoeuvre and made many more steering corrections during the exercise. These findings suggest that skills learned on the simulator do transfer to real driving environments, but negative skills may also transfer if the simulator differs from the real system in some important way. More recently, Morgan et al. (2011) reported that newly qualified professional drivers, who received most or their training in a simulator, possess skills equivalent to those trained in an actual vehicle. However, whether experienced professional drivers can benefit from simulator-based training, given that their mental models for driving a commercial vehicle are already well-established also has yet to be evaluated.

One commonly used approach to evaluating training was put forward in the 1950s by Donald Kirkpatrick (1959, cited in Rothmann and Cooper, 2008). He proposed that training programmes can be evaluated at four progressively important levels. The first level is "Reaction", which evaluates what the participants thought and felt about the training. This level normally involves asking participants to complete satisfaction or smile sheets. The second level of Kirkpatrick's model, the "Learning" stage, investigates whether the training has resulted in an increase in knowledge, skills or a change in attitudes. The evaluation at this level normally occurs towards the end of the training course in the form of a test of knowledge or skill. The third level of the model investigates whether the training has resulted in a change in the targeted behaviour. In other words have the skills and knowledge learned during the course been transferred into the workplace. This evaluation normally occurs 3–6 months after the training course while the trainee is performing the job. The last stage of Kirkpatrick's model assesses the final "Results" or outcomes of the training programme. In other words, has the programme resulted in the expected monetary savings or overall organisational improvements in performance? Therefore, the current study evaluated an eco-driving training programme for bus drivers, using levels 1–3 of Kirkpatrick's model.

2. Method

2.1. Experimental design

The study consisted of two groups, a treatment group and a control group. There were 29 bus drivers in the treatment group and 18 in the control group. However, in each training session a maximum of six bus drivers took part at any one time. In all cases at the start of the session the drivers were told what the study would involve, in terms of their time, but they were not told the aim of the study was to investigate whether or not simulator training was effective in reducing fuel consumption. The experimental process for the two groups is outlined below (Figs. 2 and 3).

2.1.1. Treatment group

2.1.1.1. Familiarisation drive. Firstly, trainees in the treatment group had a practice drive in the bus simulator (see Fig. 1) before any measures were taken. This was simply to ensure the participants were familiarised with the simulator, how it worked and how it behaved. Prior to beginning the practice run each driver received a number and four sets of six random numbers were generated. These random numbers were used to determine the order in which the drivers took part in the subsequent bus simulator sessions.

2.1.1.2. Test run 1. Test run 1 took place before the eco-driving course and involved a drive in the simulator of approximately 8 minutes. There were six different routes used, meaning that each bus driver drove a different route. The simulator routes were designed based upon real routes and real conditions within the Helsinki area. A number of performance measures were taken during the drive, such as fuel consumption, distance driven and time taken to complete the drive. After they completed the drive participants were asked to complete one of the two versions of the questionnaire (A or B, see Section 2.3) which asked questions about their eco-driving knowledge, mental workload, simulator face validity and whether they were experiencing any symptoms of simulator sickness. The order in which the drivers received the different versions of the questionnaires were counterbalanced to prevent order effects.

2.1.1.3. Eco-driving course. The drivers in the treatment group were taught the five golden rules of eco-driving in a classroom environment involving a maximum of six drivers at any one time. In summary, these golden rules are:

- Anticipate traffic flow.
- Maintain a steady speed at a low RPM.
- Shift up gears early.
- Check tyre pressures frequently at least once a month and before driving at high speed.
- Consider any extra energy used (e.g., air conditioning) costs fuel and money.

Fig. 1. Picture of the simulator.

Each individual then received coaching on putting these principles into practice while driving the bus simulator. The one day course was run on all occasions by the same instructor and took approximately 7 hours in total.

2.1.1.4. Test run 2. Test run 2 was undertaken following the completion of the eco-driving course. During the test drive the same driving measures were recorded (e.g. fuel consumption, distance driven) and after they finished the drive they were again asked to complete one of the two versions of the questionnaire (A or B, a different version to the one they completed after test run 1) which again asked questions about their eco-driving knowledge, mental workload, face validity and simulator sickness.

2.1.2. Control group

The training process for the control group was similar to that of the treatment group, except they did not have any training in eco-driving. However, in order to make the two groups as equivalent as possible, instead of training in eco-driving the control group received first aid training (see Fig. 3).

2.2. Participants

Participants came from two separate bus companies operating in and around the Helsinki region of Finland. Most of the treatment group came from a single company, while all of the drivers in the control group came from the other company. There were 18 drivers in the control group (first aid training) and 29 drivers in the eco-driving group. The number of participants included in the study was determined by the number of drivers the two bus companies made available, along with time and financial constraints.

The average age was 47 years old, with those in the eco-driving group being slightly older ($M = 47.9$, $SD = 11.3$) than those in the first aid group ($M = 42.2$, $SD = 13.1$). There were statistically significant differences in the years' experience driving a bus and annual mileage, with the eco-driving group reporting more experience ($M = 19.1$, $SD = 10.7$, $p = 0.011$) and a higher annual mileage ($M = 61777$, $SD = 23728$, $p = 0.002$) than the control group (First Aid group). For the First Aid group the average experience was 10.5 years ($SD = 11.1$) and the number of kilometres per year was 39428 ($SD = 11119$).

2.3. Measures

The questionnaire consisted of four scales, which measured mental workload, symptoms of simulator sickness, simulation face validity and knowledge of eco-driving. Although there were two versions of the questionnaire (A & B) the only difference between these two versions was in the last section of the questionnaire (eco-driving knowledge). Each version of the questionnaire (A & B) contained different eco-driving questions so that the drivers were not asked exactly the same questions before and after the training (to prevent practice effects). The questions consisted of some tick the box style questions, but most of the questions required a written answer.

The NASA-TLX (Hart and Staveland, 1988) measures six aspects of mental workload (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration). The drivers were given a short explanation of each of these subscales that the driver read before rating each of the six aspects on a 100-point scale (5-points steps). Mental workload was measured to investigate whether the mental workload changed during the study and also to assure that the different scenarios were equal in terms of mental demands (as perceived individually).

Symptoms of simulator sickness were assessed using a short 10 item measure (Hooey and Gore, 1998; Stephens and Groeger, 2009). This required the drivers to report the degree to which they experienced each of the 10 symptoms of simulator sickness (e.g., blurred vision, dizziness, nausea, sweating) on a four point scale, which ranged from "None" to "Severe".

Face Validity was measured by asking the driver to report the degree to which the bus simulation they had just experienced looked, felt and behaved like a real bus. Based upon previous research (Muncie, 2006), three questions were used to measure face validity: *In comparison to a real bus, how realistic was this simulation?*; *In comparison to a real bus, how realistic was this behaviour of the bus (e.g., acceleration, steering, braking)?*; *In comparison to a real bus route, how realistic was this*

Fig. 2. Summary of treatment group.

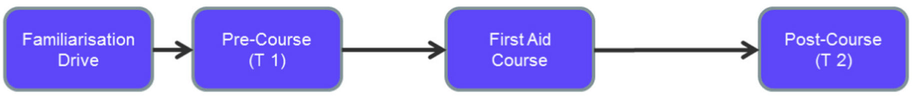

Fig. 3. Summary of control (first aid) group.

simulated bus route?. The three questions were answered on a five point Likert scale, which ranged from "Not very realistic" to "Very realistic" This information is important for the perceived validity of the training and also for training transfer. In other words, if the face validity is too low then this will detract from the perceived validity of the training and may also reduce the transfer of training into the workplace.

The drivers were also asked their age, sex, annual mileage and the number of years that they had held a bus driving licence. In addition, a number of measures were collected during the simulator drives, such as: fuel consumed, average speed, CO_2 produced, average fuel economy, number of times the brake was used, number of full stops, time to complete the route and kilometres driven.

2.4. Simulator

The simulator consisted of a Volvo (model 8700) bus body, based on an electro-pneumatic motion platform with four axes of movement. Motion was controlled by simulation software based on four clustered PC's, by data transfer with UDP over IP protocol. The driver's view is about 220 degrees, plus mirrors. The views are generated by three screens and four projectors, fixed to the bus body. The simulation also includes projections of the traffic behind in both wing mirrors and rear view mirror and displays RPM and speed on the dashboard (as a standard bus). The projectors are Hitachi CW210 extra short throw projectors with a native resolution of 1280×800. The front screens are $2700\ \text{mm} \times 1500$ and the side screens are $2000\ \text{m} \times 1500\ \text{mm}$. The front screen is controlled by two synchronised projectors with one each for the side views.

2.5. Fuel consumption data

Fuel consumption data were measured at the driver level and was collected as they filled up the bus fuel tank at the end of the day. Unfortunately it was not possible to get data for all drivers in each group due to a large number of issues, including: bus drivers going on holiday, bus drivers changing routes, changing bus type (i.e., from a large bus to a small bus or large mini-van), faulty data and driver turnover. At Time 1 fuel consumption data were obtained for 24 drivers in the Treatment group and 12 from the First Aid group, but six of those in the Treatment group were missing at least one of the other two time periods (leaving 16 in the Treatment group). Furthermore, due to company differences it was not possible to get exactly the same data in exactly the same format for the control and treatment groups. The fuel data from the treatment group was the average for the 1.5 months before the eco-driving training, 1.5 months after the training and for a one week period six months after training. For the control group, data was provided one week before the first aid training, one full week immediately following the training and one full week six months after the first aid training took place. Therefore, although the data from the control (First Aid) group was not over the same length of time as for the treatment group, this data was a subsample of the same time period.

3. Results

3.1. Simulator data

Table 1 summarises the data collected from the simulator for the two groups. For those drivers who were not instructed in eco-driving techniques (i.e., the First Aid, or Control Group), there were no significant differences between the first and second assessment on any of the measures collected by the simulator. For the eco-driving group there were no differences for: time, distance, average speed, braking, the number of full stops, CO_2 produced or the total fuel consumed. However, there was a significant reduction in the average fuel consumption figures.

However, as can be seen in Table 1 there was a slight (but non-significant) decrease in the number of stops, as well as some other slight differences in the journey characteristics. Therefore, in order to check whether the reduction in the average fuel consumption was due to any of the other variables (i.e., we would not like this improvement to be due to a reduction in the number of full stops, as in most cases these full stops are a part of a bus driver's job when collecting and dropping off passengers), the differences for the two time periods were calculated ($T1$–$T2$) and a regression was used to predict the reduction in average fuel consumption. This regression was not significant ($F = 1.75$, $p = 0.163$) and none of the variables predicted the observed decrease in average fuel consumption. Therefore, as the improvement only occurred in the eco-driving group the improvements must be due to the application of eco-driving techniques. In other words, the eco-driving training seemed to have enabled those in the treatment group to drive in a more economical manner.

3.2. Questionnaires

Table 2 shows the results of the measurement of the six aspects of workload, simulator sickness and how realistic the simulator and simulation were perceived to be. This shows that the drivers reported a very low level of simulator sickness (2.67–3.17, in a possible range of 0–40) and there were no differences at all on the overall measure of simulator sickness (10-items combined) for the treatment or control group.

Table 1
Results from the simulator drives.

	Drive	Eco-driving	First aid
Time driven	1	8.17 (1.62)	8.24 (1.01)
	2	7.85 (1.24)	8.00 (0.96)
		NS	NS
Distance travelled	1	3.24 (0.43)	3.27 (0.31)
	2	3.27 (0.36)	3.27 (0.29)
		NS	NS
Average speed	1	24.19 (6.09)	23.79 (4.55)
	2	25.00 (4.92)	24.46 (4.25)
		NS	NS
Braking	1	13.72 (3.22)	16.25 (4.27)
	2	12.59 (2.90)	16.30 (3.81)
		NS	NS
Full stops	1	8.14 (2.55)	8.10 (1.92)
	2	7.41 (2.23)	8.75 (1.65)
		NS	NS
Fuel consumed	1	1.04 (0.16)	1.19 (0.16)
	2	1.03 (0.16)	1.19 (0.22)
		NS	NS
CO_2 produced	1	2.76 (0.43)	2.95 (0.46)
	2	2.75 (0.42)	3.18 (0.60)
		NS	NS
Average fuel consumption	1	34.14 (4.87)	34.77 (5.90)
	2	29.97 (2.75)	36.42 (7.19)
		0.000	NS

Table 2
Workload, simulator sickness and realism.

	Treatment group *M* (SD)			Control group *M* (SD)		
	*T*1	*T*2	Sig.	*T*1	*T*2	Sig.
Mental	48.28 (18.34)	35.72 (25.33)	.014	38.61 (22.74)	47.50 (24.81)	.106
Physical	39.14 (18.08)	23.07 (19.51)	.001	29.72 (25.29)	33.33 (23.70)	.381
Temporal	42.59 (19.94)	33.62 (23.30)	.044	27.78 (20.88)	35.56 (25.66)	.144
Performance	49.48 (18.14)	40.62 (23.78)	.065	30.28 (22.78)	38.89 (25.53)	.144
Effort	55.34 (19.36)	48.00 (22.75)	.131	49.44 (26.17)	58.33 (24.73)	.118
Frustration	28.39 (20.10)	24.29 (24.18)	.415	18.33 (14.95)	22.22 (22.51)	.310
Real Simulation	2.43 (0.68)	2.28 (0.75)	.357	2.44 (1.14)	2.62 (0.93)	.370
Real Bus Behaviour	2.52 (0.81)	2.33 (0.92)	.196	2.71 (1.11)	2.59 (.78)	.614
Real Bus Route	2.82 (0.87)	2.61 (0.98)	.414	3.09 (.94)	3.24 (.77)	.428
Simulator Sickness	2.96 (3.25)	2.67 (3.50)	.506	3.17 (3.81)	3.11 (2.85)	.921

The bus drivers were also asked how realistic the simulation was in comparison to a real bus, how realistic the behaviour of the bus was (e.g., steering, acceleration, braking) and how realistic was the simulated route. For the first question drivers were on average reporting that the bus simulation was halfway between "A little realistic" and "Quite realistic" (average ranged from 2.28 to 2.62, on a five point scale). With regards to the realism of the bus performance, drivers rated the bus as halfway between "A little realistic" and "Quite realistic" (average ranged from 2.33 to 2.71). The realism of the bus route was rated slightly higher than the other two measures of realism, with a range of 2.61 to 3.24.

However, there were significant reductions for three of the six measures of mental workload (mental, physical and temporal) in the treatment group. This reduction in workload for these three measures cannot be due to practice or the routes being easier, as the control group did not demonstrate a workload reduction and the routes were the same six routes,

Table 3
Knowledge of eco-driving.

	*T*1 *M* (SD)	*T*2 *M* (SD)	Difference	Sig.
Control group	2.65 (1.41)	2.32 (1.19)	−0.32	0.420
Eco-training	2.93 (1.60)	3.26 (1.83)	+0.33	0.417

Table 4
Fuel economy figures for both groups at three time periods.

	Before *M* (SD)	After *M* (SD)	6 Months *M* (SD)	*t*	Sig.
Eco-driving	37.09 (4.12)	33.24 (1.97)	31.73 (3.55)	>4.32	0.001
First aid	41.76 (3.96)	41.38 (4.16)	42.11 (4.53)	<1	NS

selected at random. Perhaps once the bus drivers knew what was expected of them, following the eco-driving training, the mental, physical and temporal demands were reduced.

3.3. Knowledge of eco-driving

The bus drivers in both groups (First Aid training and Eco-driving training) were also asked to answer questions which tested their knowledge of eco-driving before and after the training. Two versions of the questionnaire had to be developed so that the drivers did not simply remember the questions and the answers from time 1 to time 2. These were presented in counterbalanced order to prevent order effects.

For the control group there was a slight decrease in the eco-driving knowledge from *T*1 to *T*2, but this difference was not significant (Table 3). Conversely, for the eco-driving group there was a slight improvement in the eco-driving knowledge, but this again was not significant.

3.4. Actual fuel economy

In order to test whether the eco-driving training transferred to the workplace the average fuel consumption figures were obtained from the two bus companies that took part in the trials. However, due to a number of constraints the data obtained from the two companies were not exactly the same. For the company from which most of the treatment group originated, aggregated data were obtained for each bus driver for the 1.5 months immediately preceding the eco-driving training, the 1.5 months immediately following the training and finally one full week of fuel consumption data was collected six months after the eco-driving course. For the control or First Aid group, average fuel economy figures were obtained for each driver one week prior to the training, one week after the training and for one week six months after the training. Although not ideal, the figures for those in the First Aid group were collected at exactly the same time as those from the treatment group, but just over a shorter time period.

Data could not be obtained from all of the drivers in both groups due to a number of problems. These included driver turnover, annual leave being taken (and thus data missing for one period), changes in bus type (i.e., changing from a big bus to a very small), changes in route driven and some incomplete data. Therefore, fuel economy figures were obtained for 16 drivers from the treatment group and 12 of the First Aid or Control group.

Paired t-tests were used to compare whether the two fuel economy figures after the eco-driving course were significantly different to the fuel economy figures beforehand. For the treatment group the results showed that the average fuel economy figures were significantly better immediately after the eco-driver training ($t = 4.32$, $p = .001$) and also six months after the training ($t = 5.53$, $p < .000$). This means that the fuel economy figures significantly improved immediately following the eco-driving training and this improvement appeared to be maintained after six months. In contrast, the mean fuel economy figures for the 12 bus drivers in the Control group did not change significantly immediately after the first aid training or six months after (see Table 4).

4. Discussion

The present study investigated whether bus drivers trained in eco-driving techniques, using a bus simulator, could put these into practice in a bus simulator and also whether this learning would be implemented in the workplace. Bus drivers who were trained in eco-driving techniques improved their average fuel economy on the simulator immediately after the training, while those in the control group did not. More importantly these techniques were also implemented in the workplace, with an 11.6% improvement in fuel economy immediately following the training and this was further increased to 16.9% after six months. Furthermore, as there was no change in the fuel economy figures for those in the control group we can rule out a substantial number of alternative explanations for the improvements in fuel economy. In other words, as the companies operated in the same general area of Helsinki, Finland they would be exposed to similar changes in traffic conditions (e.g., holiday traffic), are likely to experience similar fluctuations in passenger demand and the same weather conditions.

The weather conditions did change during the course of the study, but they were the same for the two groups. For the treatment group and control groups the average temperatures, respectively, were: before the training −4.5C and −3.1C, immediately after the intervention +5.4C and +5.3C and +14.1C and +13.5C after six month. Furthermore, although there was no precipitation for the control group before the training (the treatment group experienced an average of 1.0 mm/day). For the period immediately following the treatment the treatment group experienced an average of 0.9 mm, while the control group received an average of 1.4 mm/day. The precipitation during the week long measure six months after the training found that there was 2.4 mm/day for the treatment group, while the control group experienced and an average of 2.5 mm/day. As the weather conditions were the same for both groups over the three time periods we can say that any changes in fuel consumption were not due to weather differences.

This is the first study to adequately demonstrate that training in eco-driving techniques can result in improvements in driving behaviour and that this training can also be transferred into the workplace. This research builds upon the small amount of previous evidence which has reported eco-driving training to result in an increase in fuel economy in general (Andrieu and St Pierre, 2012; Beusen et al., 2009; Rutty et al., 2013) and for bus drivers (Carrese et al., 2013; Strömberg and Karlsson, 2013; Wahlberg, 2007; Zarkadoula et al., 2007). However, the present study is a more robust test of simulator-based training in eco-driving as there were far more bus drivers included than in some peer reviewed research (e.g. Zarkadoula et al., 2007) and in contrast to all the peer reviewed research amongst car, truck and bus drivers (Andrieu and St Pierre, 2012; Beusen et al., 2009; Carrese et al., 2013; Reed et al., 2012; Rutty et al., 2013; Strayer and Drews, 2003; Strömberg and Karlsson, 2013; Wahlberg, 2007; Zarkadoula et al., 2007), this study also included a control group.

The fuel economy improvement observed here six months after the eco-driving training was 16.9%, which was not as high as the 27% improvement Carrese et al. (2013) suggested would be possible via changing driving behaviour. There could be a number of reasons why this estimated improvement was not reached, including the difficulty in balancing the potentially conflicting goals of being a bus driver (i.e., adhering to the bus timetable vs. driving economically). This explanation is supported by previous research which has shown that performance on fuel saving goals is reduced when drivers have to manage fuel and time savings together (Dogan et al., 2011). Undoubtedly this will often be the case with bus drivers. Furthermore, providing drivers with the knowledge required to improve their driving behaviour does not mean that they will be motivated to put these principles fully into practice. Therefore, companies should also pair the training with behavioural change techniques to encourage and motivate drivers to improve their eco-driving performance.

This study concentrated on training the drivers in how to drive in an economical fashion, but no attempt was made to change the driver's attitudes towards eco-driving or their intentions to engage in eco-driving. As research has shown that the Theory of Planned behaviour explains between 46% and 61% of the variance in employee intentions to engage in environmental behaviours (Greaves et al., 2013), focusing on improving the TPB constructs may also be a productive manner for encouraging eco-driving. In other words, improving bus drivers attitudes to eco-driving, describing positive social norms and increasing their perceived behavioural control may result in an additional improvement in economical driving.

The results from the questionnaires were not as clear as the simulator and company fuel consumption data. There was no significant change in eco-driving knowledge for either the control or treatment groups, although there was a slight improvement for the treatment group and a slight decrement for the control group. There are a number of possible reasons for this, one of which was that the bus drivers did not take the completion of the questionnaires (or this section) seriously and only made a partial attempt at obtaining a good score. In support of this explanation is the fact that it was apparent to an independent observer (and several members of the training company) that the bus drivers did not like completing these questionnaires. This was particularly the case for the second questionnaire which was late in the afternoon and close to when they were due to go home.

Another potential cause of these questionnaire results is that a number of questions were very specific (e.g., how often to check tyre pressure) and a correct answer required a very specific answer. However, in order to make a substantial improvement in fuel economy a driver need only to implement the main principles of eco-driving rather than remembering precise details. Furthermore, the items included in this section of the questionnaire were based upon a short summary of eco-driving principles, rather than directly from the contents of the eco-driving course, which was in Finnish. Therefore, there may have been small differences between the document on which the questions were developed and the way in which it was actually taught. However, as the questionnaires were checked by the trainer and training company beforehand, it is unlikely that this would have been a substantial issue. Irrespective of the questionnaire results, the simulator data and actual fuel consumption information appear to indicate that the drivers clearly understood and were able to implement at least some of the principles of eco-driving.

Interestingly, although there were no changes in mental workload for the control group, there were significant reductions for three of the six measures of mental workload (mental, physical and temporal) in the treatment group. This reduction in workload for these three measures cannot be due to practice or the routes being easier, as the control group did not change and the routes were the same six routes selected at random. Perhaps once the bus drivers knew what was expected of them (driving in an economical manner), following the eco-driving training, the mental, physical and temporal demands were reduced. As the control group did not get to experience this same revelation, their mental workload did not change. The current authors are not aware of this pattern of change being reported elsewhere.

4.1. Limitations

As with all applied research there were a number of limitations with the study reported here. Firstly, it was not possible to obtain fuel consumption figures for all of those who attended the eco-driving and first aid courses. This was due to the many issues previously mentioned, such as drivers changing bus routes, changing bus types, going on holiday and leaving the company. Participant attrition is simply a fact of conducting research in the workplace and while the reduction in numbers was not ideal the adverse impact was not as substantial as in previous research. For example, driver attrition resulted in Strömberg and Karlsson (2013) losing their control group and being forced to combine their two different treatment groups in order to have an acceptable number of drivers. Participant attrition also meant that it was not possible to adequately determine the cost-benefit of conducting this intervention after a year. There were also additional factors which precluded this, such as the fact that after the six month period was up both groups received additional training which may also have influenced fuel consumption.

Another issue with regards to the fuel consumption figures was that those in the treatment group all came from the same bus company. It is therefore possible that the improvements in fuel economy could be related to a company-wide improvement in the fuel economy of that particular bus company, or that drivers in this bus company were already improving their fuel economy. In order to address this issue overall company fuel consumption figures were requested from that bus company, but due to the time required to compile this information the bus company personnel were not able to provide this. In addition, we also tried to collect data from several individuals who were in the treatment group, but from a different company. Unfortunately the data available were incomplete, with full data for all six before the eco-driving training, for three immediately after training (−10.8%, −11.2% and +2.4%) and for only one after six months (−11.6%). Therefore, there is some limited evidence to suggest that the decrease found in the treatment group was not confined to the single company and that the improvement occurred irrespective of which company the bus drivers came from.

Another potential explanation for the improvement in fuel economy could be that the bus drivers in the treatment group knew their fuel consumption was being measured and therefore altered their behaviour because of this. However, this fact was not mentioned to the bus drivers in either group, as both companies routinely collected fuel consumption data. Therefore, no change was made to how and what was collected from the bus drivers from pre to post treatment, meaning that this is unlikely to account for the obtained results.

One strange finding that is not easily explained is that fact that although the simulator figures demonstrated a significant reduction in average fuel economy for the treatment group, there was not a significant reduction in CO_2 produced. This is unusual, as the average fuel consumption and CO_2 figures should be directly proportional. We were not able to explain this finding. However, the improvement in fuel economy reported by the simulator was supported by actual fuel economy figures and improving the actual fuel economy is the main aim of the training.

4.2. Conclusions

The present study has shown that simulator-based eco-driving training has the potential to significantly improve the average fuel economy of professional drivers. In the present study fuel economy was improved on average by 11.6% immediately after the training and by 16.9% six months after the training. The use of simulator-based eco-driving training seems to have led to a behavioural change that was sustained over a reasonable period of time. If this level of improvement could be made throughout the EU road transport sector it would greatly contribute to the EU meeting its environmental goals. Furthermore, this research also demonstrated that training drivers in eco-driving has the potential to greatly reduce fuel-related costs for transport companies. However, future research is needed to test whether these findings can be generalised to other parts of the road transport sector and also to investigate whether these improvements are maintained for longer than six months.

Acknowledgements

SIMTEB (Simulator-based training for European Bus Drivers) was funded by the Leonardo Da Vinchi – Lifelong Learning Partnership. This project had the following partners: Cranfield University (UK), TTS – Työtehoseura (Finland), Korsisaari (Finland), TT-C Training Technology-Consulting (Germany), BBZ (Germany), Technical University of Dortmund (Germany), Coreys (France), Team Simrac (Finland), and OPNV Akademie Austria.

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