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# Evaluating the impacts of the demerit points system on traffic law violations and driver involvement in road accidents in Israel

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**Abstract**

Demerit points systems (DPS) have been used in many countries as a means for improving road safety, by monitoring traffic law violations of drivers and applying corrective measures to repeat offenders, while knowledge on their safety impacts is yet incomplete. This study examined the DPS impacts on committing traffic offenses and accident involvement of drivers, in Israel, based on files of the national Licensing Authority and complementary accident files. Models were developed to evaluate changes in violation and accident rates of drivers, who underwent the DPS corrective measures, in after the treatment related to the before period, and accounting for changes observed in the matched comparison-groups. The findings showed that during the three-year period after the measures' implementation, the decrease in committing violations was of 70%, and simultaneously, there was a decrease in drivers' accident involvement, on average, of 1% in severe accidents and of 11% in total injury accidents. The effects were consistent across various groups of drivers by the corrective measures applied and the type of license. The study results support the continued use of the DPS, to improve drivers' behaviors and road safety. To increase its impacts at the national level, the DPS implementation should be supported by stable police enforcement and publicity efforts.

**Keywords** Demerit points system, Road safety, Evaluation, Traffic law violations, Drivers, Accident involvement, Statistical models, Matched comparison-groups

## 1 Introduction

Road accidents impose substantial economic and social burdens throughout the world [46]. Recognizing the role of human factors in accident occurrences [26] and the prevalence of traffic law violations in driver behaviors [7, 15, 27], progressive penalty points systems have become common in traffic legislation in many countries [9, 22, 39, 42]. A points system relies on the assumption that violating behavior should be addressed more strongly if it is repetitive and refers to more dangerous offences, i.e. those increasing accident and injury risks [39, 42]. It presents a means for monitoring traffic violations committed by drivers, including corrective measures [22, 39, 42]. Beyond the prescribed punishment for the commission of each violation (e.g., fines), demerit points are accrued to the driver, in line with the violation's severity. In accordance with the number of points accumulated over a predesignated time-period, the driver is obligated to undergo "corrective measures", e.g. a driving improvement course; license suspension, with retaking a theory or practical driving test to reinstate the driver's license, etc. As assumed [9, 22, 39, 42], the points system contributes to road safety in three ways: by preventing unsafe behaviors, due to the fear of accumulating demerit

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points; by correcting dangerous behaviors through remedial driver education, and by detaining traffic offenders.

In general, there are two ways for applying penalty points, either by subtracting points from an initial sum granted together with the driving license, or by accumulating demerit points for the violations committed, until reaching a predetermined threshold, when the driving license becomes restricted. The latter form is known as a "demerit points system" (DPS), and is more common in the world today [9, 22]. As reported in [9], a DPS is being utilized in 24 European countries and in 44 countries worldwide. A points system appears among the interventions which are recommended by leading international bodies for improving road safety in the country [9, 16, 17, 21]. As indicated [17, 35, 42], DPS is typically supported by the public, due to the higher perceived justice when the system focuses on repeat offenders, rather than on occasional violators, and seems to be more egalitarian than monetary fines. Consequently, many countries have been adopting or upgrading such points systems, in the past decades, as part of their efforts to promote national safety goals and programs [9, 28, 39, 42].

In Israel, the DPS has been implemented since 1968, while in 2003, a "revised DPS" was introduced, with changes in the points attributed to specific offences, re-definition of the supervised violation list and changing the rules of assigning corrective measures on drivers. Although the introduction of the revised DPS was announced in 2003, the implementation of relevant changes in the traffic regulations took longer, so that the full application of the corrective measures (particularly regarding "license revocation", see details in Sec.3) commenced only in 2012. In light of the great public interest in the revised DPS [4] and a lack of previous assessments in Israel, the Ministry of Transport initiated a study, aiming to evaluate the DPS impacts on road safety. This paper provides the study's evaluation results, which, for the first time, quantifies the safety impacts of DPS, in Israel.

Concerning the international context, it should be noted that in several countries, e.g. Italy, Spain, Denmark, Australia, China, studies were conducted aiming to evaluate DPS's influence on safety, by analyzing changes in traffic violations, road user behaviors, or traffic accidents (see Sec.2). They generally found positive DPS contributions to road safety, in terms of reductions in injury, or lower rates of unsafe behaviors. However, the impact indicators estimated and the extent of the effects reported by previous research differ widely, depending on data available for a study and the evaluation framework applied. For example, in Italy and Spain, several studies examined the DPS impacts on safety, see [5, 12, 47] and [3, 8, 36] respectively, while the results indicated positive trends but were not identical. In general, ultimate answers as to the DPS safety effects are not available and further research is needed to extend the international knowledge on the topic, especially for countries where such evaluations were not performed in the past. The current study intended to contribute to this gap.

In addition, previous studies mainly considered a DPS, which was introduced at a certain year and examined changes in traffic injury or behaviors, during the immediate after vs. before years [2, 3, 5, 8, 12, 33, 36, 45, 47]. However, when the DPS introduction takes a period of years, as happened with the revised DPS in Israel, previous research findings are not explicitly relevant and thus this study had the potential to provide a novel contribution with regard to DPS safety impacts, in such a different context. Moreover, a long period of the DPS introduction imposed challenges on the assessment framework, which could not follow a traditional approach of previous research with monitoring general injury or behavior indicators in a country or region, due to changes in many factors, which occurred in the transport system over the years, and thus could mask the DPS effects. Hence, this study developed a different and novel approach for the estimation of DPS safety impacts, which were analyzed at a micro-level, based on an examination of changes in the commission of traffic violations and involvement in accidents among the drivers treated by the system.

Furthermore, in this study, the research team received for the analyses the Israeli Licensing Authority (ILA) database, which comprised the information on all Israeli drivers, including their traffic violations, convictions, and the corrective measures utilized within the DPS framework, in the years 2003–2015. Additionally, a special file was prepared by Israel's Central Bureau of Statistics (CBS), which incorporated data on all drivers involved in road accidents in the same period, and allowed to identify drivers in the ILA files. Thus, the study relied on a unique dataset enabling to examine the DPS's impacts, by analysing changes in committing traffic violations and accident involvement of drivers, who passed specific DPS corrective measures. The use of national files on drivers' violations and accidents, while accounting for detailed DPS processes, was not applied by previous international research. Thus, the current study had also a potential to provide in-depth insights in the safety impacts of DPS, which are not available yet in the international literature.

The remainder of the paper is structured as follows. Section 2 provides a concise summary of previous research on DPS impacts on road safety. Section 3 describes the study methodology, with data sources, the definition of evaluation framework, data preparation and models' development. Section 4 provides the study results as to the DPS impacts on traffic law violations and drivers' involvement in accidents, followed by a general discussion in Sect. 5 and conclusions in Sect. 6.

## 2 Previous research on DPS impacts on road safety

Among the studies that investigated DPS effects on road safety three groups can be seen: studies that examined changes in drivers' behaviors or traffic violations; those that examined accident changes; and those that assessed the efficiency of corrective measures. In the first group, DPS research usually focused on violations or unsafe behaviors that were directly linked to severe traffic injury, e.g. speeding, impaired driving, non-use of seatbelts, red-light running [7, 15], assuming that decreasing the number of such violations would indicate positive impacts of DPS on safety [22, 39]. This approach can be supported by more general studies (not related to DPS), which showed that drivers convicted for a greater number of violations were also involved in more accidents than drivers with fewer or no violations [18, 23, 29, 42].

Studies that investigated DPS impacts, found [1, 5, 12, 24, 33, 43, 45, 47] that DPS introduction was related to a reduction in serious traffic violations, yet, the impact magnitude varied between the studies and countries. For example, in Italy, after DPS implementation, a 73% reduction was observed in speeding tickets [5], while, in Australia, a 6% reduction in repeated speed offenses was reported [45] and, in the UAE, no impact on traffic speeds was found [33]. Another Italian study [12] reported that DPS contributed to a 39% reduction in speeding, non-use of seatbelts in cars and non-use of helmets by motorcyclists, while more serious violations, leading to license revocation (e.g., driving 40 + km/h above the speed limit, or impaired driving) only decreased by 11%. A study in Denmark found [1] that after DPS initiation, drivers who received demerit points were involved in fewer violations, compared to drivers who were only fined; the violation rates decreased by 15%-30%, and the probability for additional violations by drivers who accumulated one or more points—by 11%-20%. To note, most studies in this group examined DPS impacts over a time-period of under two years from DPS implementation, while longer-term effects were not examined.

The second group of studies estimated DPS influence on the occurrence of traffic accidents or injury, in a certain region or country [2, 3, 5, 8, 12, 25, 36, 47]. For example, the analysis of time-series of road accident fatalities and casualties in one region of Italy showed [47] that in the first eighteen months of DPS implementation, there was an 18% decrease in fatalities and 19% less casualties. Another Italian study found [5] that on motorways, following DPS initiation, in the periods when drops in speed tickets per driver were observed, there was also a decrease in the number of total and fatal accidents, of 18% and 26%, respectively. An additional Italian study found [12] that having controlled for seasonality, presence of police and traffic cameras, weather conditions and gasoline price (as exposure substitute), DPS contributed to significant reductions in the number of accidents, casualties, and fatalities, to the extent of 10%, 15% and 25%. A study in Hong Kong reported [43] that after the revision of point-scale for red-light violations, the number of associated accidents decreased by 23% and of related casualties—by 29%.

In Spain, the analysis of monthly time-series of interurban highway fatalities across the country showed [3] that DPS had a significant decreasing effect, at an average rate of 11%-14%, maintained through the monitoring period of about three years. As suggested [3], such a positive and relatively prolonged influence of DPS was related to the increased enforcement and media coverage on road safety issues, in the country. Another Spanish study [8], found a DPS impact in a decreased number of fatalities on motorways, by a rate of 13%, which lasted for at least two years from DPS implementation. A third study from Spain [36] examined changes in driver involvement in road accidents over a period of a year-and-a-half from DPS inception, as opposed to six years before, and found risk reductions for various driver groups, which were higher, of 10% or more, in the case of severe accidents. The study [36] also noted a correspondence between the higher reduction in severe injuries and the fact that DPS primarily penalizes drivers for committing serious traffic violations.

A meta-analysis of DPS effects on road accidents summarizing findings of over 20 studies conducted in eleven countries [9] showed that DPS introduction was associated with decreases of 15%-20% in the numbers of accidents, casualties and fatalities, but the impact typically disappeared in a period of less than 18 months, on average, apparently, due to the lack of sufficient enforcement. Similarly, a survey of points systems in European countries revealed [22, 28] that DPS impacts on the number of accidents and casualties lasted between 6–12 months; an explanation for that was that enforcement and media support that had accompanied initial DPS implementation decreased over-time.

Concerning the safety impacts of corrective measures included in DPS, the European study summarized [22, 28, 39] that research findings on the topic are not definitive. For example, as to "warning letters", a summary international estimate indicated [15] that their use was associated with a 10% reduction in accidents, while a more recent Canadian study reported a 7.5% reduction [31]. Regarding "improvement courses", the international estimate suggested [15] that they reduced accidents by 11%, while French studies [13, 38] found an improvement in reported driver behaviors (e.g. a decrease in speeding) amid course attendees as opposed to comparison-groups. Nonetheless, in American studies, driving courses were not found to reduce violations and accidents [34], and were even associated with higher accident rates among participating drivers vs. a comparison-group [19]. International experience suggests [41] that remedial courses are more effective when combined with license revocation. Additional research found [31, 32, 34] that license suspension or revocation was more effective in decreasing traffic violations and accident involvement by drivers than other corrective measures.

## 3 Methodology

As indicated in Sec.1, in Israel, the DPS has been implemented since 1968, originally with 2, 4 and 6 points for single offences. In 2003, a "revised DPS" was introduced, with the following changes [4]: setting two additional degrees of violation severity (8 and 10 points), reducing the list of violation types supervised (73 instead of 300, previously), and changing the rules of assigning corrective measures on drivers, with a particular focus on heavy repeat offenders. The current system monitors all licensed Israeli drivers, without distinguishing novice drivers or different types of licenses. The Israeli DPS is based on accumulating demerit points resulting from convictions for the violations committed, where four thresholds are defined with associated corrective measures, as follows [44]: (1) the accumulation of 12–22 points within two years requires passing a basic driving improvement course ("basic course"); (2) amassing 24–34 points over 4 years requires the completion of an advanced remedial driving course ("advanced course"); (3) having accumulated 36 or more points in four years, the driving license is suspended for three months and can only be renewed after passing the theory driving test ("license suspension"); and (4) after accumulating 36 or more points for the second time in four years, a more detailed investigation is applied regarding the time-gaps between the violations, and either the driving license is suspended for three months with passing the theory test, or the license is revoked for nine months, with mandatory medical testing, and both theory and practical driving tests to be passed for the license to be reinstated ("license revocation"). The ILA manages the digital data regarding the DPS implementation. The data are updated every few days, in accordance with Police reports on convicted drivers. For each driver, the point sums are compared to the DPS thresholds; if the threshold was crossed, the driver receives a notification on the obligatory corrective action.

As we mentioned above, due to the long period of the revised DPS introduction (actually, until 2012), a traditional framework with assessing changes in safety or driver behaviors at a macro-level was inapplicable, being aware of many changes that occurred in the transport system over the years. Therefore, to evaluate the DPS influence on road safety, we developed "micro-models" (according to model classifications in [18, 22]), which examined drivers' involvement in the commission of traffic violations and road accidents.

The model allows to estimate the frequency of incidents (violations or accidents) among drivers who underwent the DPS corrective measures ("treatment-group") in the period following the measure's implementation ("after"), as opposed to the frequency of such incidents, prior to the measure's implementation ("before"), while the change in the treatment-group is compared to the incident change in the similar periods among drivers who did not pass the corrective measures ("comparison-group"). In other words, we applied a "before-after" design, with a comparison-group, as preferred in safety assessments, e.g. [15], whereas incident changes observed in the comparison-group reflected the influence of other factors rather than the intervention examined. Other confounding factors may include, for example, changes (between the before and after periods) in road and traffic conditions, police enforcement, vehicle fleet, weather conditions, etc. In line with international research on the topic [1, 9, 22, 42], the underlying assumption of the study was that, if, for offenders who have undergone the DPS corrective measures a reduced incident frequency was estimated in the after relative to before period, it would indicate a positive safety impact of the DPS.

### 3.1 Data from the ILA

For the study, the ILA provided data files about licensed drivers, traffic violations and convictions, and actions—the corrective measures administered, during 2003–2015 (the files were with fictitious drivers' identifications). The files contained data on all drivers in the country who had committed at least one violation during the reported period. The drivers' file included information on 2,385,937 persons, with categories of their licenses. Following cross-checks of drivers' birth-years and license categories vs. the regulations' demands [44], 0.4% erroneous records were removed. The convictions' file included data on all the violations committed by the drivers and their resulting convictions, when each record represented an event with one or more violations by a specific driver; it contained 9,333,373 records.

The actions' file incorporated data on all the corrective measures taken against offending drivers during the period 12.2003–1.2016; it had 1,352,658 records. In coordination with the ILA, from the file were removed: "fictitious actions" – those that were not actually performed despite the records in the national system (e.g., "license revocation" that was not implemented during the transition period; the "administrative cancellation" of certain activities), and erroneous records (e.g., with a discrepancy between the year of test and that of commencing the corrective measure); in total, 12.9% of records were removed. In line with the DPS regulations in Israel (see above), the actions' file included five *types* of corrective measures, which are: 1 – a "basic course"; 2 – an "advanced course"; 3

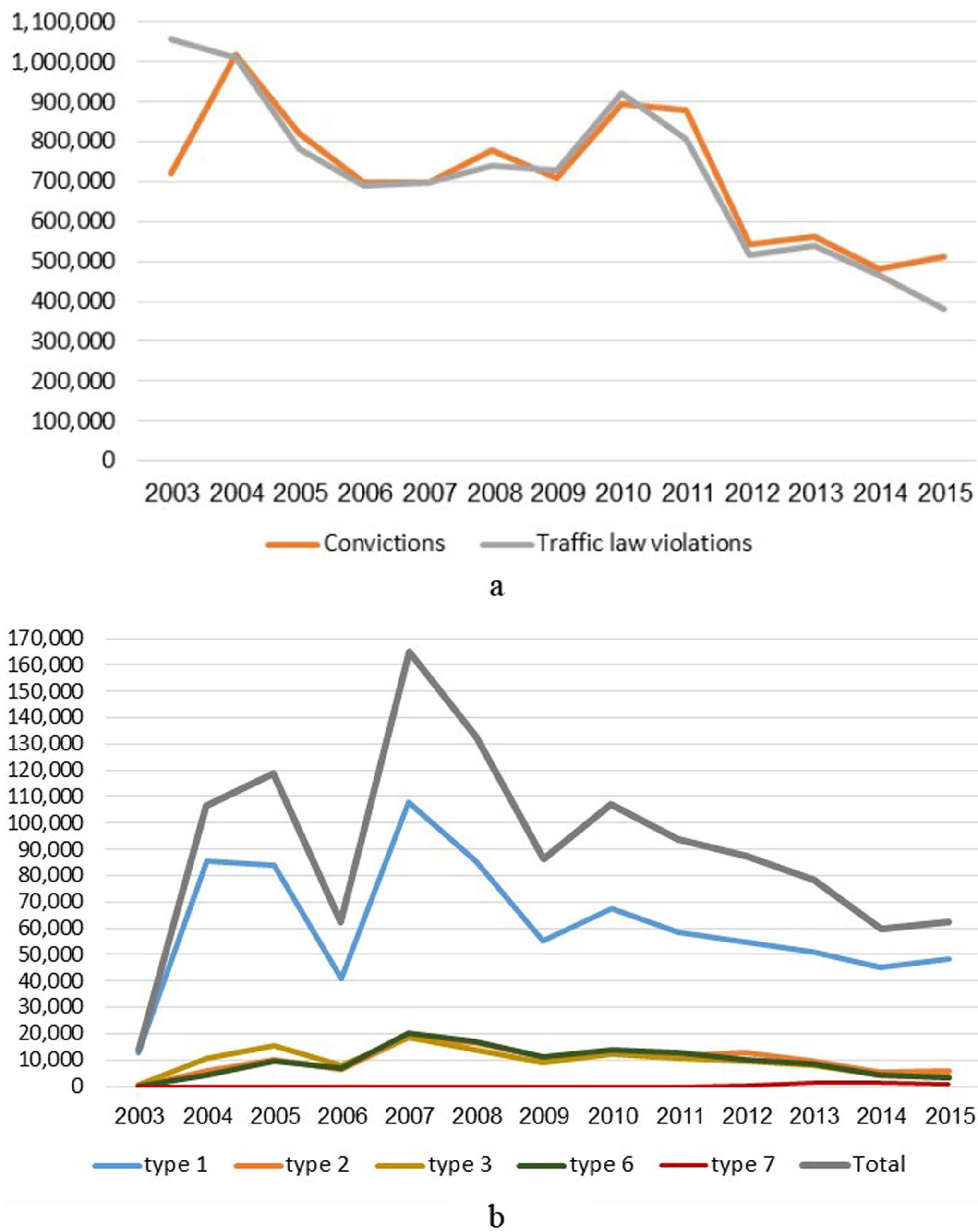


**Fig. 1** Overview of the numbers of traffic law violations and reported convictions (**a**), and of corrective measures commenced by the DPS in Israel (**b**), in 2003–2015

– another "advanced course"; 6 – "license suspension"; 7 – "license revocation" (the type codes as in the original file).

Initially, the data of the convictions' and actions' files were explored, to review the over-time developments and the extent of various actions applied. Figure 1 presents an overview of the number of drivers' violations and convictions per year, and of the number of actions, by type, that were commenced by the ILA within the DPS. One can see (Fig. 1a) that the process of catching traffic violations was unstable over-time, so that the amount of apprehended drivers decreased by half over a decade, from over a million violations per year in 2003–2004, to about half a million in 2012–2014. Similarly, the scope of corrective actions implemented was not uniform over-time (Fig. 1b): the number of actions taken was greater in the mid-2000s, while, in later years, there was a decrease in the activities, apparently due to the decrease in the amount of traffic violations that were caught.

In addition, the total figures show that, over the years, most of the corrective measures completed were of type 1

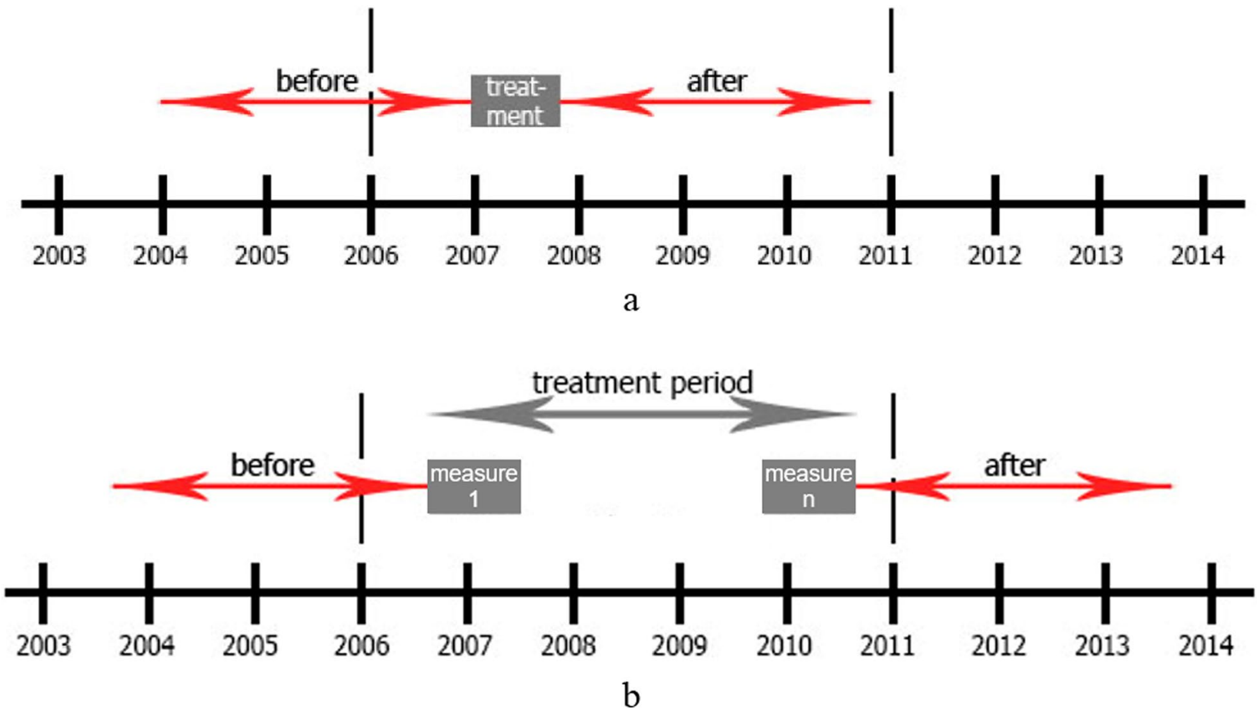


**Fig. 2** Definitions of before and after periods for drivers who passed the DPS corrective measures ("treatment"), in the study timespan: **a** – case with one measure, **b** – case with several measures

(68%); the scopes of types 2, 3, and 6 were each over 10% of all the actions taken, indicating that between 107,000–112,000 drivers underwent each of these actions. As to type 7 ("license revocation"), this corrective measure was applied after 2012, so that only a small sample of drivers (235) was found to complete it; thus, this type was excluded from further analyses.

### 3.2 The analysis of impacts on traffic law violations

#### *3.2.1 The evaluation framework and data preparation*

To adjust the model for estimating the DPS impact on committing traffic violations, a "timespan" for intervention—the corrective measures' implementation, was defined, between 2006–2011. This timespan was selected to enable drivers' monitoring in three-year periods, before and after the implementation of corrective means, by using the study database.[1] As a "treatment-group", we selected drivers who experienced the corrective actions during the timespan. For each driver in the treatment-group, on the time axis, the intervention period was indicated—from start to completion of his/her corrective measures, together with the periods before and after the intervention (Fig. 2).

The data showed that during the period defined, the drivers in the treatment-group underwent between 1–5 corrective actions, and that there was a wide range of combinations of those. Hence, to define the categories of treatment for the analysis, with regard to all the drivers in the treatment-group, we examined the combination frequencies and the order of corrective actions, together with their meanings and time-gaps, aiming to create a restricted list of categories with consistent meanings. As a result, 12 categories of treatment were suggested as detailed in Table 1, representing single measures or combinations of corrective measures (of types 1, 2, 3, and 6, as introduced above). For example, category "1" reflects a basic course, which was applied once or twice with a time-gap below two years; category "1_1" reflects several basic courses (i.e. basic course was applied two or more times, with a time-gap over two years); category "1_2" corresponds to a case when basic course was followed by an advanced course of type 2; and so on.

Following the definition of treatment categories, each driver in the treatment-group was assigned a month for starting and another for completing his/her treatment, with three-year before and after periods, respectively (Fig. 2a). When the driver underwent several corrective measures, the before period was defined as the three years going back in time from the start of the first action, and the after period referred to the three years going forward in time from the completion of the last action (Fig. 2b). Moreover, there were cases where the driver had additional corrective measures before or after the delineated timespan; in such

[1] For years 2003–2014; year 2015 was omitted, since the data might not have included all the convictions, due to delays in the system.

**Table 1** Descriptive statistics of the database for violation analysis: drivers' characteristics*

| Characteristic (*variable* in the model) | *Categories* and distribution of drivers according to categories |
|---|---|
| Drivers' group: treatment or comparison (*treat*) | *Treatment* 245,458 (50.04%), *comparison* 245,040 (49.96%) |
| Period: before or after (*after*) | *Before* (50%), *after* (50%) |
| Drivers' group by type of treatment& (*group*) | *(1)* 1, B (46.6%); *(2)* 1_1, B (0.8%); *(3)* 1_2, B (2.9%); *(4)* 1_2_6, B (1.4%); *(5)* 1_3, B (2.2%); *(6)* 1_3_6, B (1.2%); *(7)* 1_6, B (1.7%); *(8)* 2, B (0.9%); *(9)* 2_6, B (0.7%); *(10)* 3, B (1.0%); *(11)* 3_6, B (0.8%); *(12)* 6, B (7.0%); *(13)* 1, other (19.5%); *(14)* 1_1, other (0.6%); *(15)* 1_2, other (1.8%); *(16)* 1_2_6, other (1.1%); *(17)* 1_3, other (1.3%); *(18)* 1_3_6, other (0.8%); *(19)* 1_6, other (1.0%); *(20)* 2, other (0.6%); *(21)* 2_6, other (0.6%); *(22)* 3, other (0.6%); *(23)* 3_6, other (0.5%); *(24)* 6, other (4.3%) |
| City of driver's residence, by religion (*religion*) | *Jewish city* (62.6%), *Arab city* (16.3%), *mixed city* (21.1%) |
| City of driver's residence, by size (*size*) | *Small* (44.3%), *medium-sized* (25.2%), *large* (30.5%) |
| Age-groups of drivers** (*age*) | *Below 25* (4.1%); *passed 25* (14.2%); *between 25–44* (43.2%); *passed 45* (10.3%); *between 45–64* (22.5%); *passed 65* (3.2%); *65 or more* (2.4%) |

*N = 490,498. &According to combinations of categories of corrective measures (1,2,3,6) and type of license (B or other). **In the study timespan, based on driver's birth-year; "passed"—the driver changed age-group during the timespan

cases, the before or after period was truncated, respectively. Yet, the data prepared for the analysis showed that the number of such cases was negligible (ca. 1%).

Furthermore, to enable a separate consideration of the DPS impact on various drivers, we wanted to distinguish between drivers of private cars only and professional drivers. Thus, the final groups of treated-drivers, for the analysis, were defined by a combination of the corrective measures' categories (as explained above) and two categories of driving licenses, i.e. B-type (restricted to light vehicles below 3.5 ton) or other types—C,D,E categories for driving various trucks or buses, according to the traffic regulations [44]. This way, 24 groups of drivers were defined, by the characteristic of "type of treatment" (see Table 1). (To note, if a driver had several licenses, the classification was made in accordance with the highest type of license kept. Drivers with A-license only, for motorcycles, were omitted.)

For each driver in the treatment-group, the number of violations was counted in the before and after periods based on dates of their commission; violations that occurred on the same day were counted as one incident. Only violations with demerit points were included in the data. The violation statistics revealed problems in the DPS functioning, for example, substantial delays, in some cases, between the violation occurrence and conviction, or between the date of the last violation and the beginning of corrective action. In such cases, the before periods were corrected to exclude the "waiting" time in the system.

The comparison-group of drivers was built using a separate dataset, which included all the drivers, from the ILA files, who had not undergone any corrective measure in 2003–2014. For each driver in the treatment-group, a comparison-driver was matched, with the same background characteristics such as age-group, license category, and the categories of the city of residence regarding its size, religion and geographic area. For some professional drivers' groups (according to the "type of treatment"), the comparison-driver dataset could not supply all the cases with fully matched characteristics to the treated-drivers, thus, in some cases, a partial match was applied while in others a lack of fitted comparison-driver was indicated. However, in the final database, both issues were minor, with 0.1%-3% lacking cases and 0.3%-4.8% approximated cases, across the professional drivers' groups. For each comparison-driver, all his/her violations were extracted and counted in the time-periods that corresponded to the before and after periods of the matched driver from the treatment-group.

#### *3.2.2 Model development*

Being aware of variations in the drivers' monitoring periods, the analysis used a relative indicator—the number of violations divided by period length, which was brought to a common form of the violation rate per 1,000 days (designated as *v2time*). For this indicator, an explanatory model was adjusted, accounting for the characteristics of: driver group (treatment or comparison), period (before or after), type of treatment (24 groups as explained in Sec.3.2.1), driver's age-group (7 categories), size and religion of the city of driver's residence. The city groups by religion were applied as defined by the CBS [10]; they reflect the leading population groups in the city, i.e. Jewish, Arab or mixed. With regard to city size, three categories were defined in this study: small (up to 50,000 residents), medium-sized (50,000–200,000) and large (over 200,000), in line with common city size classifications in local research, e.g. [20]. As to the driver's age-groups, we applied a subdivision into seven categories, aiming to distinguish between young, middle-aged and elderly drivers and also to indicate whether the driver remained in the same age-group or moved between them, during the period considered. All categories can be seen in Table 1. (The information of driver gender was not available in the ILA files and thus was not included in the analyses).

As the dependent variable in the model, we used a square-root transformation of the violations' indicator, in the form of *sqrt(v2time+0.5)*, that was chosen following a Box-Cox analysis [37] by means of the TRANSREG procedure of Statistical Analysis Software (SAS) [40]. First, we attempted to fit a model using the treated-drivers' database only, with the explanatory variables introduced above and maintaining the possibility for interaction between the period and other variables. However, due to the database enormity, this attempt did not succeed: the MIXED procedure of SAS failed, ending with "infinite likelihood", while the use of a HPMIXED procedure demanded heavy computer resources that were unavailable. Hence, we decided to attempt a model based on a sample of offending drivers, which was prepared by selecting 1,000–2,000 drivers from each group, by the type of treatment. Using the sample, the model fit was successful, and showed significant impacts of all the explanatory variables and of most interactions.

Therefore, the main model in this analysis – based on the data of treated-drivers and comparison-drivers together, was fitted using a special dataset which included samples of 1,000 treated-drivers from each of 24 groups (by the type of treatment) and corresponding samples of 1,000 comparison-drivers. The model was adjusted using a SAS generalized linear mixed models (GLIMMIX) procedure [40], while applying all the explanatory variables as detailed above and enabling interactions between the variables of period, "treatment"[2] and other variables. The latter was kept to allow for different relations between the explanatory variables and the dependent, in before and after periods and for different groups of drivers.

To check possible correlations between potential explanatory variables, we calculated Spearman rank correlation coefficients for the three ordinal explanatory variables—driver's age-group, size and religion of the city of residence (corresponding variables *age*, *size* and *religion* in Table 1). Results showed the values of −0.094 (between *age* and *religion*), 0.0097 (between *size* and *age*) and 0.268 (between *size* and *religion*), which according to Cohen [11] can be judged as very small to small correlations. Thus, all the variables remained for the model development.

The model formulation was as follows:

$$
\begin{aligned}
\widehat{sq\_y}_{it} = {} & \widehat{\beta}_0 + \widehat{\beta}_{I\_treat\_0} * I\_treat\_0(i) + \sum\nolimits_{j=1}^{23} \widehat{\beta}_{I\_group\_j} * I\_group\_j(i) \\
& + \sum\nolimits_{j=1}^{23} \widehat{\beta}_{I\_treat\_0*I\_group\_j} * I\_treat\_0(i) * I\_group\_j(i) + \widehat{\beta}_{I\_after\_0} * I\_after\_0(it) \\
& + \widehat{\beta}_{I\_treat\_0*I\_after\_0} * I\_treat\_0(i) * I\_after\_0(it) \\
& + \sum\nolimits_{j=1}^{23} \widehat{\beta}_{I\_after\_0*I\_group\_j} * I\_after\_0(it) * I\_group\_j(i) \\
& + \sum\nolimits_{j=1}^{23} \widehat{\beta}_{I\_treat\_0*I\_after\_0*I\_group\_j} * I\_treat\_0(i) * I\_after\_0(it) * I\_group\_j(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_religion\_r} * I\_religion\_r(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_treat\_0*I\_religion\_r} * I\_treat\_0(i) * I\_religion\_r(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_after\_0*I\_religion\_r} * I\_after\_0(it) * I\_religion\_r(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_treat\_0*I\_after\_0*I\_religion\_r} * I\_treat\_0(i) * I\_after\_0(it) * I\_religion\_r(i) \\
& + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_size\_s} * I\_size\_s(i) + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_treat\_0*I\_size\_s} * I\_treat\_0(i) * I\_size\_s(i) \\
& + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_after\_0*I\_size\_s} * I\_after\_0(it) * I\_size\_s(i) \\
& + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_treat\_0*I\_after\_0*I\_size\_s} * I\_treat\_0(i) * I\_after\_0(it) * I\_size\_s(i) \\
& + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_age\_a} * I\_age\_a(i) + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_treat\_0*I\_age\_a} * I\_treat\_0(i) * I\_age\_a(i) \\
& + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_after\_0*I\_age\_a} * I\_after\_0(it) * I\_age\_a(i) \\
& + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_treat\_0*I\_after\_0*I\_age\_a} * I\_treat\_0(i) * I\_after\_0(it) * I\_age\_a(i)
\end{aligned}
$$

[2] In all models, this variable means a distinction between treatment-group and comparison-group drivers.

where: $\widehat{y}_{it} = (\widehat{sq\_y}_{it})^2 - 0.5$

$$I\_treat\_0 = \begin{cases} 1 & \text{if driver in comparison-group} \\ 0 & \text{if driver in treatment-group} \end{cases}$$

$$I\_group\_j = \begin{cases} 1 & \text{if driver in group (treatment-type) } j \\ 0 & \text{otherwise} \end{cases} \quad j = 1, \ldots, 23$$

$$I\_after\_0 = \begin{cases} 1 & \text{if period is before} \\ 0 & \text{if period is after} \end{cases}$$

$$I\_religion\_r = \begin{cases} 1 & \text{if religion of city} = r \\ 0 & \text{otherwise} \end{cases} \quad r = 1, 2$$

$$I\_size\_s = \begin{cases} 1 & \text{if size of city} = s \\ 0 & \text{otherwise} \end{cases} \quad s = 1, 2$$

$$I\_age\_a = \begin{cases} 1 & \text{if age\_group} = a \\ 0 & \text{otherwise} \end{cases} \quad a = 1, \ldots, 6$$

$y_{it}$ is the value fitted to violation indicator of driver $i$ in period $t$; $\beta$ – model coefficients.

Based on the model, post hoc comparisons were conducted to estimate differences in violation rates among the drivers' groups in the after versus before period. To that end, least-squares means were estimated for various combinations of variables of "treatment", period and driver group (by the type of treatment) and differences were assessed with Bonferroni adjustment for multiple comparisons [6].

### 3.3 The analysis of impacts on involvement in road accidents

#### *3.3.1 Data preparation*

An approach similar to the one described above served for the evaluation of DPS impacts on driver's involvement in road accidents, regarding the definitions of the timeframe and the treatment-groups and comparison-groups of drivers.

For the study, the CBS created a special file, that included all Israeli drivers involved in traffic accidents, in 2003–2014 (a total of 332,461 records). Beside the details on accident dates and severity, each driver was given a fictitious identificator (calculated in accordance with a formula received from the ILA) that enabled the accident data to be assigned to the treatment-group and comparison-group drivers, in the study database.

For each driver, the number of accidents was counted in the before and after period, including total injury accidents and severe accidents (with fatalities and serious injuries, together). The sums showed that drivers in the treatment-group were involved in a total of 32,828 injury accidents during both periods, of which 3,444 were severe, while drivers in the comparison-group were involved in 13,356 injury accidents, of which 1,390 were severe. Since drivers' involvement in accidents was rare and much lower relative to committing violations (for example, in the treatment-group, 91.8% of drivers were not involved in any accident in the before and 95.8% in the after period), a further generalization was needed as to the definition of drivers' groups by the type of treatment. Hence, for the accident analysis, four categories of corrective measures were composed, with the following meanings: a basic course only; an advanced course as a single measure or in combination with a basic course; a basic or advanced course, or both, followed by license suspension; and license suspension only. In combination with two license categories (private car drivers or professional drivers), eight groups of drivers were defined, by the type of treatment.

#### *3.3.2 Model development*

As in the case of violations, the model was fitted to a relative indicator—the number of accidents per 1,000 days (designated as *a2time*), while separate models were developed for total injury accidents and severe accidents. Each model used the combined data on both treatment-group and comparison-group drivers, with all their characteristics (as introduced in Sec.3.2.2).

Trial runs of count data models, such as a negative binomial model, failed; thus, models were developed with variables transformed. Following a Box-Cox analysis of the dependent variable [37], a logarithmic transformation was chosen, written as: *log(a2time + 0.05)*, with a constant added, to prevent a transformation of zero value. In each model, we enabled interactions of the period and "treatment" variables with other variables, so they might have different relations with the dependent one, in various periods and for different drivers' groups. Each model was accomplished by means of the SAS GLIMMIX procedure [40], with a normal distribution. The model had the form:

$$
\begin{aligned}
\widehat{Log}\left(y_{it}+0.05\right) = {} & \widehat{\beta}_0 + \widehat{\beta}_{I\_treat\_0} * I\_treat\_0(i) + \sum\nolimits_{j=1}^{7} \widehat{\beta}_{I\_n\_group\_j} * I\_n\_group\_j(i) \\
& + \sum\nolimits_{j=1}^{7} \widehat{\beta}_{I\_after\_0 * I\_n\_group\_j} * I\_after\_0(it) * I\_n\_group\_j(i) \\
& + \sum\nolimits_{j=1}^{7} \widehat{\beta}_{I\_treat\_0 * I\_after\_0 * I\_n\_group\_j} * I\_treat\_0(i) * I\_after\_0(it) * I\_n\_group\_j(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_religion\_r} * I\_religion\_r(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_treat\_0 * I\_religion\_r} * I\_treat\_0(i) * I\_religion\_r(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_after\_0 * I\_religion\_r} * I\_after\_0(it) * I\_religion\_r(i) \\
& + \sum\nolimits_{r=1}^{2} \widehat{\beta}_{I\_treat\_0 * I\_after\_0 * I\_religion\_r} * I\_treat\_0(i) * I\_after\_0(it) * I\_religion\_r(i) \\
& + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_size\_s} * I\_size\_s(i) + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_treat\_0 * I\_size\_s} * I\_treat\_0(i) * I\_size\_s(i) \\
& + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_after\_0 * I\_size\_s} * I\_after\_0(it) * I\_size\_s(i) \\
& + \sum\nolimits_{s=1}^{2} \widehat{\beta}_{I\_treat\_0 * I\_after\_0 * I\_size\_s} * I\_treat\_0(i) * I\_after\_0(it) * I\_size\_s(i) \\
& + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_age\_a} * I\_age\_a(i) + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_treat\_0 * I\_age\_a} * I\_treat\_0(i) * I\_age\_a(i) \\
& + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_after\_0 * I\_age\_a} * I\_after\_0(it) * I\_age\_a(i) \\
& + \sum\nolimits_{a=1}^{6} \widehat{\beta}_{I\_treat\_0 * I\_after\_0 * I\_age\_a} * I\_treat\_0(i) * I\_after\_0(it) * I\_age\_a(i)
\end{aligned}
$$

where: $\widehat{y}_{it} = e^{(\widehat{Log}(y_{it}+0.05))} - 0.05$

$$I\_treat\_0 = \begin{cases} 1 & \text{if driver in comparison-group} \\ 0 & \text{if driver in treatment-group} \end{cases}$$

$$I\_n\_group\_j = \begin{cases} 1 & \text{if driver in group (treatment-type)} j \\ 0 & \text{otherwise} \end{cases} \quad j = 1, \ldots, 7$$

$$I\_after\_0 = \begin{cases} 1 & \text{if period is before} \\ 0 & \text{if period is after} \end{cases}$$

$$I\_religion\_r = \begin{cases} 1 & \text{if religion of city} = r \\ 0 & \text{otherwise} \end{cases} \quad r = 1, 2$$

$$I\_size\_s = \begin{cases} 1 & \text{if size of city} = s \\ 0 & \text{otherwise} \end{cases} \quad s = 1, 2$$

$$I\_age\_a = \begin{cases} 1 & \text{if age\_group} = a \\ 0 & \text{otherwise} \end{cases} \quad a = 1, \ldots, 6$$

$y_{it}$ is the fitted value for accident indicator for driver $i$ in period $t$; $\beta$ – model coefficients.

Post hoc comparisons were conducted using the model to estimate differences in accident rates and their significance, in the groups of drivers in the after versus before period. Comparisons were based on the estimation of least-squares means while using a Bonferroni correction for multiple comparisons [6]. Furthermore, *odd ratios* of accident changes in the treatment-group vs. comparison-group and their significance, were estimated, with Holm's adjustment for multiple comparisons [14].

## 4 Results

### 4.1 Impacts of DPS measures on traffic law violations

Tables 1, 2 present descriptive statistics of the database prepared for the violation analysis, with variable definitions. The descriptive statistics of the violation rates indicated (Table 2), that drivers from the treatment-group had a remarkable decrease in committing violations in the after period related to before, while among the comparison-group drivers only slight, if any, differences were observed between the periods; similar trends were observed when examining the driver groups by the type of treatment.

As stated above, the model was developed using a dataset of equal samples from all (48) driver groups (i.e.

**Table 2** Descriptive statistics of the database for violation analysis: violation frequencies

| Indicator | Drivers' group, period | Mean | s.d. | min | max |
|---|---|---|---|---|---|
| Violations' number per driver | Treatment, before | 2.95 | 1.52 | 1 | 28 |
| | Treatment, after | 1.03 | 1.44 | 0 | 28 |
| | Comparison, before | 0.26 | 0.50 | 0 | 4 |
| | Comparison, after | 0.30 | 0.53 | 0 | 4 |
| Violation rate per 1,000 days *(v2time)* | Treatment, before | 3.40 | 2.17 | 0.9 | 100.0 |
| | Treatment, after | 0.94 | 1.32 | 0 | 25.5 |
| | Comparison, before | 0.28 | 0.59 | 0 | 26.3 |
| | Comparison, after | 0.27 | 0.48 | 0 | 4.0 |

treated- and comparison-drivers, subdivided by the type of treatment); the model calculations lasted over 26 h. To note, enlarging the samples did not alter the model outcomes. (The model developed with its fit statistics is presented in the Additional file 1.) The estimated $R^2$ of the model was 0.677, which according to Cohen [11] indicates a substantial fit.[3] In the model fitted, the effects of all the explanatory variables were significant ($p < 0.0001$) as well as the effects of most interactions between the period and "treatment" variables and other variables, except for a few insignificant interactions (e.g., treatment—religion of city; period—city size).

Based on the model, mean estimates of the violation indicators and their changes in the after compared to before period were assessed, for all driver groups – Table 3. The results showed that in the treatment-group of drivers as a whole and in the driver groups with various types of treatment, significant reductions were found in the violation rates in the after-treatment period related to before ($p < 0.0001$), while the comparison-groups showed no differences in violation indicators between the two periods. On average, the rate of traffic violations per 1,000 days fell by 73% among the drivers who passed the DPS corrective measures, but only by 4% among the comparison-drivers, between the similar periods.

Figure 3 exhibits the percentage reductions in the violation rates, in the after vs. the before period, among various driver groups. One can see that, following the implementation of corrective measures, there was a substantial decrease in the violation rates, ranging 69%-82%, for drivers of private vehicles, and ranging 64%-80% in the case of professional drivers. The same indicator showed no consistent change in the groups of comparison-drivers of private cars, and a slight decrease in the groups of professional comparison-drivers. Both for drivers of private vehicles and professional drivers, stronger effects on violation rates were observed for the corrective measures such as: the basic course (category "1"); the advanced courses ("2", "3"); and when the drivers underwent, first, the basic course and then the advanced course ("1–2", "1–3"). On the contrary, a repetition of the basic course ("1–1") and the combinations of corrective means with a license suspension (treatment-types with "6"), had lower impacts on the commission of violations.

### 4.2 Impacts of DPS measures on driver involvement in road accidents

Tables 4, 5 provide descriptive statistics of the database that served for accident analysis, with variable definitions and raw accident rates. The accident rates indicated consistently greater differences, between the after and before periods, for the groups of treated-drivers related to comparison-drivers. A detailed data consideration revealed that, in total accidents, the differences in accident changes between the treatment and comparison-groups of drivers, were much stronger when the corrective measures were implemented in 2006, than in later years. Thus, regarding the drivers' involvement in total injury accidents, two separate models were adjusted, the first with the implementation of corrective measures in 2006 and the second model afterwards (All fitted models and their fit statistics are presented in the Additional file 1).

In the model fitted to severe accidents, significant effects were found for all the explanatory variables ($p < 0.0001$) and for the interactions between the variables of period and "treatment" with treatment-type and age-group ($p < 0.05$). In the model for total accidents and the implementation of corrective measures in 2006, a significant impact was found for all the explanatory

[3] Furthermore, being aware of the large number of driver groups included in the model, a possibility of the separation effect was considered based on Koll et al. [30]. The model was fitted to a transformed dependent value (after adding 0.05), using the normal distribution. The normal distribution has no point mass at zero, or at any other value, hence no divergence of model coefficients during the maximization of the model log-likelihood with respect to one or more of its parameters is expected due to separation. By "separation" we refer to a situation when there is a combination of regressors in the model whose value can perfectly predict an outcome. Moreover, the consequence of "separation" is the divergence of some model coefficients and their large standard errors. The analysis of the model parameters showed no evidence of such bias, see the Additional file 1.

**Table 3** Changes in violation indicators* between before and after periods, in the treatment-groups and comparison-groups of drivers

| Treatment type | 1—treatment-group, 0—comparison-group | Estimate** | St. Error | p-value | Adj P | Violation indicator in before period | Violation indicator in after period | Absolute change in indicator between before and after periods | Relative change in indicator between before and after periods, % |
|---|---|---|---|---|---|---|---|---|---|
| All | 0 | 0.005 | 0.005 | 0.286 | 1.000 | 0.234 | 0.225 | 0.008 | 3.6 |
| | 1 | 0.860 | 0.008 | < 0.0001 | < 0.0001 | 3.912 | 1.039 | 2.873 | 73.4 |
| 1 | 0 | 0.003 | 0.012 | 0.801 | 1.000 | 0.212 | 0.206 | 0.005 | 2.4 |
| | 1 | 0.750 | 0.020 | < 0.0001 | < 0.0001 | 2.611 | 0.527 | 2.084 | 79.8 |
| 2 | 0 | 0.007 | 0.012 | 0.584 | 1.000 | 0.198 | 0.187 | 0.011 | 5.6 |
| | 1 | 0.639 | 0.020 | < 0.0001 | < 0.0001 | 2.718 | 0.835 | 1.884 | 69.3 |
| 3 | 0 | −0.019 | 0.012 | 0.115 | 1.000 | 0.169 | 0.200 | −0.032 | −18.8 |
| | 1 | 0.881 | 0.020 | < 0.0001 | < 0.0001 | 3.332 | 0.658 | 2.674 | 80.2 |
| 4 | 0 | −0.009 | 0.012 | 0.459 | 1.000 | 0.199 | 0.214 | −0.015 | −7.7 |
| | 1 | 0.851 | 0.020 | < 0.0001 | < 0.0001 | 4.154 | 1.207 | 2.947 | 70.9 |
| 5 | 0 | 0.007 | 0.012 | 0.557 | 1.000 | 0.203 | 0.191 | 0.012 | 5.9 |
| | 1 | 0.850 | 0.020 | < 0.0001 | < 0.0001 | 3.147 | 0.624 | 2.523 | 80.2 |
| 6 | 0 | −0.014 | 0.012 | 0.257 | 1.000 | 0.197 | 0.221 | −0.024 | −11.9 |
| | 1 | 0.887 | 0.020 | < 0.0001 | < 0.0001 | 4.070 | 1.064 | 3.005 | 73.9 |
| 7 | 0 | 0.002 | 0.012 | 0.893 | 1.000 | 0.193 | 0.190 | 0.003 | 1.4 |
| | 1 | 0.821 | 0.020 | < 0.0001 | < 0.0001 | 4.009 | 1.197 | 2.812 | 70.1 |
| 8 | 0 | −0.016 | 0.012 | 0.187 | 1.000 | 0.183 | 0.210 | −0.027 | −14.7 |
| | 1 | 1.003 | 0.020 | < 0.0001 | < 0.0001 | 3.906 | 0.702 | 3.204 | 82.0 |
| 9 | 0 | 0.000 | 0.012 | 0.998 | 1.000 | 0.210 | 0.210 | 0.000 | 0.0 |
| | 1 | 1.033 | 0.020 | < 0.0001 | < 0.0001 | 4.886 | 1.157 | 3.728 | 76.3 |
| 10 | 0 | 0.010 | 0.012 | 0.411 | 1.000 | 0.221 | 0.203 | 0.017 | 7.7 |
| | 1 | 0.963 | 0.020 | < 0.0001 | < 0.0001 | 3.874 | 0.773 | 3.101 | 80.0 |
| 11 | 0 | −0.004 | 0.012 | 0.759 | 1.000 | 0.201 | 0.207 | −0.006 | −3.2 |
| | 1 | 1.050 | 0.020 | < 0.0001 | < 0.0001 | 4.945 | 1.149 | 3.797 | 76.8 |
| 12 | 0 | −0.027 | 0.012 | 0.030 | 1.000 | 0.164 | 0.208 | −0.044 | −27.0 |
| | 1 | 0.948 | 0.020 | < 0.0001 | < 0.0001 | 5.006 | 1.455 | 3.551 | 70.9 |
| 13 | 0 | −0.013 | 0.012 | 0.289 | 1.000 | 0.235 | 0.257 | −0.022 | −9.4 |
| | 1 | 0.690 | 0.020 | < 0.0001 | < 0.0001 | 2.741 | 0.732 | 2.009 | 73.3 |
| 14 | 0 | −0.014 | 0.012 | 0.264 | 1.000 | 0.243 | 0.266 | −0.024 | −9.8 |
| | 1 | 0.641 | 0.020 | < 0.0001 | < 0.0001 | 2.902 | 0.948 | 1.954 | 67.3 |
| 15 | 0 | 0.018 | 0.012 | 0.132 | 1.000 | 0.267 | 0.235 | 0.032 | 11.9 |
| | 1 | 0.820 | 0.020 | < 0.0001 | < 0.0001 | 3.372 | 0.817 | 2.554 | 75.8 |
| 16 | 0 | 0.020 | 0.012 | 0.110 | 1.000 | 0.273 | 0.239 | 0.034 | 12.5 |
| | 1 | 0.778 | 0.020 | < 0.0001 | < 0.0001 | 4.117 | 1.380 | 2.737 | 66.5 |
| 17 | 0 | 0.014 | 0.012 | 0.264 | 1.000 | 0.266 | 0.242 | 0.024 | 9.0 |
| | 1 | 0.794 | 0.020 | < 0.0001 | < 0.0001 | 3.299 | 0.834 | 2.465 | 74.7 |
| 18 | 0 | 0.004 | 0.012 | 0.734 | 1.000 | 0.253 | 0.245 | 0.007 | 2.9 |
| | 1 | 0.736 | 0.020 | < 0.0001 | < 0.0001 | 4.028 | 1.436 | 2.591 | 64.3 |
| 19 | 0 | 0.015 | 0.012 | 0.214 | 1.000 | 0.266 | 0.239 | 0.026 | 9.9 |
| | 1 | 0.764 | 0.020 | < 0.0001 | < 0.0001 | 4.050 | 1.375 | 2.676 | 66.1 |
| 20 | 0 | 0.027 | 0.012 | 0.030 | 1.000 | 0.304 | 0.257 | 0.047 | 15.5 |
| | 1 | 0.986 | 0.020 | < 0.0001 | < 0.0001 | 4.056 | 0.820 | 3.236 | 79.8 |
| 21 | 0 | 0.035 | 0.012 | 0.004 | 1.000 | 0.311 | 0.248 | 0.062 | 20.1 |
| | 1 | 0.966 | 0.020 | < 0.0001 | < 0.0001 | 5.157 | 1.496 | 3.661 | 71.0 |

**Table 3** (continued)

| Treatment type | 1—treatment-group, 0—comparison-group | Estimate** | St. Error | p-value | Adj P | Violation indicator in before period | Violation indicator in after period | Absolute change in indicator between before and after periods | Relative change in indicator between before and after periods, % |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 0 | 0.034 | 0.012 | 0.007 | 1.000 | 0.295 | 0.236 | 0.059 | 20.0 |
| | 1 | 0.940 | 0.020 | < 0.0001 | < 0.0001 | 4.110 | 0.957 | 3.153 | 76.7 |
| 23 | 0 | 0.016 | 0.012 | 0.206 | 1.000 | 0.277 | 0.250 | 0.027 | 9.9 |
| | 1 | 0.936 | 0.020 | < 0.0001 | < 0.0001 | 5.105 | 1.549 | 3.555 | 69.6 |
| 24 | 0 | 0.022 | 0.012 | 0.082 | 1.000 | 0.282 | 0.245 | 0.038 | 13.3 |
| | 1 | 0.912 | 0.020 | < 0.0001 | < 0.0001 | 5.164 | 1.654 | 3.510 | 68.0 |

*Violation rate per 1,000 days. **Difference between before and after periods in logarithmic-scale

variables as taken separately ($p < 0.0001$), as well as for most their interactions with period and "treatment" variables ($p < 0.01$). In the model for total accidents with the implementation of corrective measures after 2006, all the explanatory variables except of one (religion of city) were significant ($p < 0.0001$), and significant effects were also observed for all the interactions examined ($p < 0.01$).

Tables 6, 7 and 8 show the changes in accident rates, in various driver groups, between before and after periods, which were estimated using the models developed. In addition, *odd ratios* of accident changes in the treatment-groups versus comparison-groups of drivers are presented. Figure 4 provides a visual illustration of the percentage reduction in accident rates. The findings demonstrated that, in the groups of drivers who passed the corrective means, both in total and by the type of treatment, a significant reduction appeared in accident rates in the period after the treatment related to before, while the comparison-groups of drivers had a much smaller reduction or no change in the same indicators between the two periods. In particular:

- In severe accidents, among the treated-drivers, the accident rate decreased by 1.2% on average ($p < 0.0001$), while for the comparison-drivers it only decreased by 0.1%. In the treated-drivers' groups considered by treatment-type, the reduction in the accident indicator ranged in 0.8%-1.8% ($p < 0.001$), with stronger impacts observed for the combinations of driving improvement courses with license suspension, both among drivers of private vehicles and professional drivers (a decrease of 1.7%-1.8%). The influence of advanced course alone or license suspension alone was stronger among the professional drivers than among the drivers of private cars. The effect of basic course (only) was milder for both driver types (a decrease of 0.8–0.9%). After the adjustment for changes in the comparison-group, among the treated-drivers in total, the accident indicator showed a significant decrease of 1.1%; the impact was stronger following the combined measure of courses with license suspension (1.4%-1.8%), among both private and professional drivers ($p < 0.01$). Likewise, a stronger impact was found to be caused by an advanced course or license suspension among the professional drivers (a 1.2%-1.3% decrease, $p < 0.05$).
- In total injury accidents, after the implementation of corrective measures in 2006, the accident rate fell by 30%, on average, among the treated-drivers ($p < 0.0001$), while among the comparison-drivers, the indicator decreased by only 1%. Following the implementation of various types of corrective measures among the treated-drivers, one could observe a decrease in accident indicators, ranging 27%-33% ($p < 0.0001$), with the strongest effects seen among the professional drivers who had experienced license suspension as a single measure or combined with a course. Having adjusted for changes in the comparison-groups the effects remained substantial: a 28% reduction in accident rates among the treated-drivers in total ($p < 0.0001$), and decreases ranging in 24%-32% following various corrective measures ($p < 0.0001$), with the maximal effect being among the professional drivers, whose licenses were suspended.
- In total injury accidents when the corrective measures were implemented after 2006, the accident rate decreased by 14%, on average, among the treated-drivers in total ($p < 0.0001$), while among the comparison-drivers, the indicator decreased by 2%. Following the implementation of various types of corrective measures, the decrease in accident indicators among the treated-drivers ranged 11%-16% ($p < 0.0001$),

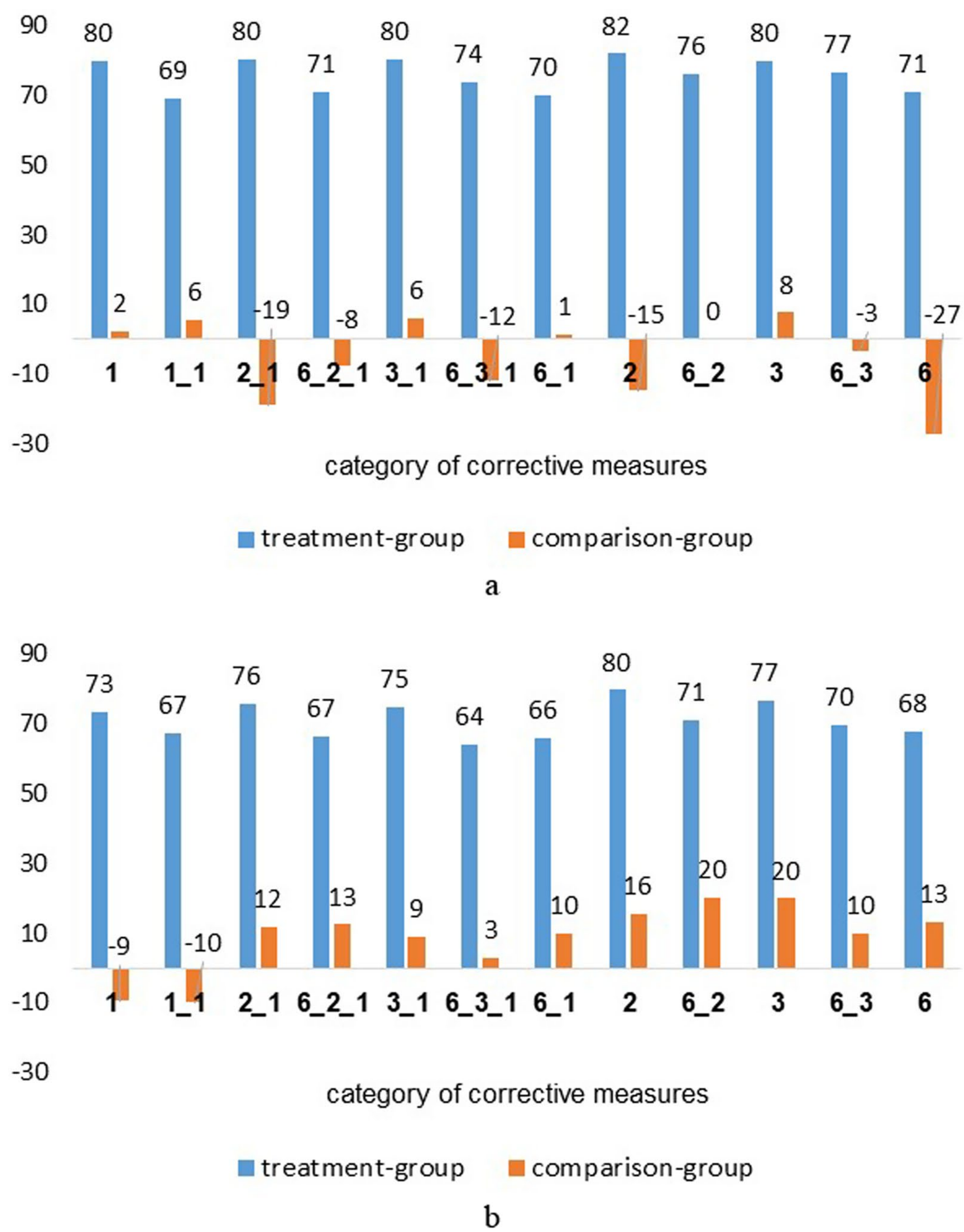


**Fig. 3** Percent of reduction in the violation indicators, in the after vs. before period, among drivers who passed the DPS corrective measures and comparison-group drivers, by categories of corrective measure: **a** – drivers of private cars (with B-license only); **b** – professional drivers (with other license types)

while in the matched groups of comparison-drivers, reductions of 1%-3% were estimated. Among both private and professional drivers, slightly stronger impacts were observed when the driver had both improvement courses and license suspension. After the adjustment for changes in the comparison-group, the results remained significant: a decrease of 11% in the accident indicator for the treated-drivers in total and decreases ranging in 9%-13%, following the implementation of various types of corrective measures ($p < 0.0001$). According to this summary examination, higher effects were found among drivers of private vehicles, who had improvement courses with license suspension later on, and among professional

**Table 4** Descriptive statistics of the database for accident analysis: drivers' characteristics*

| Characteristic (*variable* in the model) | *Categories* and distribution of drivers according to categories |
|---|---|
| Drivers' group: treatment or comparison (*treat*) | *Treatment* 251,449 (50%), *comparison* 251,449 (50%) |
| Period: before or after (*after*) | *Before* (50%), *after* (50%) |
| Drivers' group by type of treatment** (*group*) | *(1)* 1 or 1_1, B (47.9%); *(2)* 1_2 or 1_3 or 2 or 3, B (7.1%); *(3)* 1_2_6 or 1_3_6 or 1_6 or 2_6 or 3_6, B (5.6%); *(4)* 6, B (6.9%); *(5)* 1 or 1_1, other (20.1%); *(6)* 1_2 or 1_3 or 2 or 3, other (4.3%); *(7)* 1_2_6 or 1_3_6 or 1_6 or 2_6 or 3_6, other (3.9%); *(8)* 6, other (4.2%) |
| City of driver's residence, by religion (*religion*) | *Jewish city* (63.0%), *Arab city* (16.0%), *mixed city* (21.0%) |
| City of driver's residence, by size (*size*) | *Small* (44.1%), *medium-sized* (25.3%), *large* (30.6%) |
| Age-groups of drivers** (*age*) | *Below 25* (4.1%); *passed 25* (14.1%); *between 25–44* (43.2%); *passed 45* (10.3%); *between 45–64* (22.6%); *passed 65* (3.2%); *65 or more* (2.5%) |

*N = 502,898. **See comments to Table 1

**Table 5** Descriptive statistics of the database for accident analysis: accident frequencies

| Accident type | Indicator | Drivers' group, period | Mean | s.d | min | max |
|---|---|---|---|---|---|---|
| Total injury accidents | Accidents' number per driver | Treatment, before | 0.086 | 0.298 | 0 | 4 |
| | | Treatment, after | 0.044 | 0.215 | 0 | 4 |
| | | Comparison, before | 0.030 | 0.175 | 0 | 4 |
| | | Comparison, after | 0.023 | 0.156 | 0 | 4 |
| | Accident rate per 1,000 days *(a2time)* | Treatment, before | 0.079 | 0.272 | 0 | 3.65 |
| | | Treatment, after | 0.040 | 0.197 | 0 | 3.65 |
| | | Comparison, before | 0.027 | 0.160 | 0 | 3.65 |
| | | Comparison, after | 0.021 | 0.143 | 0 | 3.65 |
| Severe accidents | Accidents' number per driver | Treatment, before | 0.009 | 0.093 | 0 | 2 |
| | | Treatment, after | 0.005 | 0.071 | 0 | 2 |
| | | Comparison, before | 0.003 | 0.057 | 0 | 2 |
| | | Comparison, after | 0.002 | 0.048 | 0 | 2 |
| | Accident rate per 1,000 days *(a2time)* | Treatment, before | 0.008 | 0.085 | 0 | 1.83 |
| | | Treatment, after | 0.005 | 0.065 | 0 | 1.83 |
| | | Comparison, before | 0.003 | 0.052 | 0 | 1.83 |
| | | Comparison, after | 0.002 | 0.044 | 0 | 1.83 |

drivers, who were obligated to attend advanced courses, or had a course and license suspension.

## 5 Discussion

Demerit points systems are a means for monitoring traffic law violations committed by drivers that includes corrective penalty measures [39, 42]. Its primary goal is to deter drivers from committing repeat offences, and thus the expectation that DPS will contribute to raising road safety [17, 22, 39, 42]. In international research, DPS were found to have a positive influence on dangerous drivers' behaviors and road accidents [1–3, 5, 8, 9, 12, 24, 25, 33, 36, 43, 45, 47], although the extent of the impacts reported was not uniform and varied, depending on

**Table 6** Changes in severe accidents' indicators* between before and after periods

**a—in the treatment-groups and comparison-groups of drivers**

| Treatment type | 1—treatment-group, 0—comparison-group | *Estimate*: relation between accident indicators in before and after periods, in logarithmic-scale | St. Error | Adj P (Bonferroni) | Exp (*Estimate*) | Relative reduction in accident indicator between before and after periods, % |
|---|---|---|---|---|---|---|
| 1 | 0 | 0.0005 | 0.0008 | 0.558 | 1.000 | 0.0 |
| | 1 | 0.0088 | 0.0013 | < 0.0001 | 1.009 | 0.9 |
| 2 | 0 | 0.0008 | 0.0017 | 0.639 | 1.001 | 0.1 |
| | 1 | 0.0087 | 0.0027 | 0.001 | 1.009 | 0.9 |
| 3 | 0 | −0.0001 | 0.0019 | 0.970 | 1.000 | 0.0 |
| | 1 | 0.0176 | 0.0030 | < 0.0001 | 1.018 | 1.8 |
| 4 | 0 | 0.0007 | 0.0018 | 0.694 | 1.001 | 0.1 |
| | 1 | 0.0090 | 0.0028 | 0.001 | 1.009 | 0.9 |
| 5 | 0 | 0.0024 | 0.0011 | 0.028 | 1.002 | 0.2 |
| | 1 | 0.0076 | 0.0017 | < 0.0001 | 1.008 | 0.8 |
| 6 | 0 | 0.0025 | 0.0022 | 0.253 | 1.003 | 0.2 |
| | 1 | 0.0146 | 0.0034 | < 0.0001 | 1.015 | 1.5 |
| 7 | 0 | 0.0030 | 0.0023 | 0.193 | 1.003 | 0.3 |
| | 1 | 0.0168 | 0.0036 | < 0.0001 | 1.017 | 1.7 |
| 8 | 0 | 0.0007 | 0.0022 | 0.737 | 1.001 | 0.1 |
| | 1 | 0.0141 | 0.0035 | < 0.0001 | 1.014 | 1.4 |
| All | 0 | 0.0013 | 0.0008 | 0.113 | 1.001 | 0.1 |
| | 1 | 0.0122 | 0.0013 | < 0.0001 | 1.012 | 1.2 |

**b—in the treatment-groups vs. comparison-groups of drivers**

| Treatment type | *Odds ratio estimate*, in logarithmic-scale | St. Error | Adj P (Holm) | Exp(*Odds ratio estimate*) | Reduction in accident indicator between before and after periods, in treatment-group vs. comparison-group, % |
|---|---|---|---|---|---|
| 1 | 0.008 | 0.001 | < 0.0001 | 1.008 | 0.84 |
| 2 | 0.008 | 0.003 | 0.034 | 1.008 | 0.80 |
| 3 | 0.018 | 0.004 | < 0.0001 | 1.018 | 1.78 |
| 4 | 0.008 | 0.003 | 0.034 | 1.008 | 0.84 |
| 5 | 0.005 | 0.002 | 0.034 | 1.005 | 0.52 |
| 6 | 0.012 | 0.004 | 0.012 | 1.012 | 1.22 |
| 7 | 0.014 | 0.004 | 0.007 | 1.014 | 1.39 |
| 8 | 0.013 | 0.004 | 0.007 | 1.013 | 1.34 |
| All | 0.011 | 0.002 | < 0.0001 | 1.011 | 1.09 |

*Accident rate per 1,000 days

research framework and country. Studies that examined DPS impacts on road accidents, by means of macro-models and time-series analyses [3, 5, 8, 12, 36, 47], generally reported 10%-25% reductions in accidents or road injury as associated with DPS, while a more prolonged affect was observed in the cases when DPS implementation was accompanied by enforcement and media campaigns.

In Israel, evaluations of DPS safety impacts were not conducted in the past and this study filled this research gap. Yet, the local situation was different from international experience, since the full realization of the revised DPS lasted about a decade and was not accompanied by focused police enforcement, nor by special publicity efforts. Moreover, as the study data examinations showed, the level of actual police enforcement varied through the years of the DPS implementation. Being aware of the changes in the transport system over the years and un-uniformity of the DPS implementation,

**Table 7** Changes in injury accidents' indicators* between before and after periods, with implementation of the corrective measures in 2006

**a—in the treatment-groups and comparison-groups of drivers**

| Treatment type | 1 – treatment-group, 0—comparison-group | *Estimate*: relation between accident indicators in before and after periods, in logarithmic-scale | St. Error | Adj P (Bonferroni) | Exp (*Estimate*) | Relative reduction in accident indicator between before and after periods, % |
|---|---|---|---|---|---|---|
| 1 | 0 | −0.004 | 0.008 | 0.643 | 0.996 | −0.4 |
| | 1 | 0.261 | 0.013 | < 0.0001 | 1.298 | 29.8 |
| 2 | 0 | 0.015 | 0.012 | 0.209 | 1.015 | 1.5 |
| | 1 | 0.263 | 0.020 | < 0.0001 | 1.301 | 30.1 |
| 3 | 0 | 0.018 | 0.012 | 0.131 | 1.018 | 1.8 |
| | 1 | 0.237 | 0.019 | < 0.0001 | 1.267 | 26.7 |
| 4 | 0 | 0.001 | 0.014 | 0.921 | 1.001 | 0.1 |
| | 1 | 0.243 | 0.023 | < 0.0001 | 1.275 | 27.5 |
| 5 | 0 | −0.010 | 0.010 | 0.338 | 0.990 | −1.0 |
| | 1 | 0.240 | 0.017 | < 0.0001 | 1.271 | 27.1 |
| 6 | 0 | 0.013 | 0.015 | 0.369 | 1.014 | 1.4 |
| | 1 | 0.264 | 0.025 | < 0.0001 | 1.303 | 30.3 |
| 7 | 0 | 0.047 | 0.013 | 0.000 | 1.048 | 4.8 |
| | 1 | 0.280 | 0.022 | < 0.0001 | 1.323 | 32.3 |
| 8 | 0 | 0.008 | 0.017 | 0.623 | 1.008 | 0.8 |
| | 1 | 0.288 | 0.027 | < 0.0001 | 1.334 | 33.4 |
| All | 0 | 0.011 | 0.007 | 0.117 | 1.011 | 1.1 |
| | 1 | 0.259 | 0.012 | < 0.0001 | 1.296 | 29.6 |

**b—in the treatment-groups vs. comparison-groups of drivers**

| Treatment type | *Odds ratio estimate*, in logarithmic-scale | St. Error | Adj P (Holm) | Exp(*Odds ratio estimate*) | Reduction in accident indicator between before and after periods, in treatment-group vs. comparison-group, % |
|---|---|---|---|---|---|
| 1 | 0.264 | 0.015 | < 0.0001 | 1.302 | 30.2 |
| 2 | 0.248 | 0.023 | < 0.0001 | 1.281 | 28.1 |
| 3 | 0.219 | 0.023 | < 0.0001 | 1.244 | 24.4 |
| 4 | 0.242 | 0.027 | < 0.0001 | 1.273 | 27.3 |
| 5 | 0.250 | 0.020 | < 0.0001 | 1.283 | 28.3 |
| 6 | 0.251 | 0.029 | < 0.0001 | 1.285 | 28.5 |
| 7 | 0.233 | 0.025 | < 0.0001 | 1.262 | 26.2 |
| 8 | 0.280 | 0.032 | < 0.0001 | 1.323 | 32.3 |
| All | 0.248 | 0.014 | < 0.0001 | 1.282 | 28.2 |

*Accident rate per 1,000 days

traditional macro-analyses of changes in violations or accidents on the road network (similar to previous research) were not suitable to gain the DPS impacts, under Israeli conditions. Therefore, a different and novel approach was applied for estimating the DPS influence on safety—a micro-level analysis, which was based on an examination of changes in the commission of traffic violations and involvement in accidents among the drivers treated by the DPS system. In line with common rules of correct safety evaluations [15], the study considered the drivers who passed the DPS corrective measures in the pre-defined timespan, while changes in their violation' and accident indicators after the DPS intervention were evaluated taking into account changes observed in the same indicators among the matched comparison-drivers, who had not undergone corrective measures.

**Table 8** Changes in injury accidents' indicators* between before and after periods, with implementation of the corrective measures after 2006

**a—in the treatment-groups and comparison-groups of drivers**

| Treatment type | 1—treatment-group, 0—comparison-group | *Estimate*: relation between accident indicators in before and after periods, in logarithmic-scale | St. Error | Adj P (Bonferroni) | Exp (*Estimate*) | Relative reduction in accident indicator between before and after periods, % |
|---|---|---|---|---|---|---|
| 1 | 0 | 0.012 | 0.003 | < 0.0001 | 1.012 | 1.2 |
| | 1 | 0.114 | 0.004 | < 0.0001 | 1.120 | 12.0 |
| 2 | 0 | 0.015 | 0.006 | 0.009 | 1.015 | 1.5 |
| | 1 | 0.127 | 0.009 | < 0.0001 | 1.135 | 13.5 |
| 3 | 0 | 0.022 | 0.007 | 0.001 | 1.022 | 2.2 |
| | 1 | 0.147 | 0.010 | < 0.0001 | 1.158 | 15.8 |
| 4 | 0 | 0.013 | 0.006 | 0.028 | 1.013 | 1.3 |
| | 1 | 0.107 | 0.009 | < 0.0001 | 1.113 | 11.3 |
| 5 | 0 | 0.022 | 0.004 | < 0.0001 | 1.022 | 2.2 |
| | 1 | 0.106 | 0.005 | < 0.0001 | 1.112 | 11.2 |
| 6 | 0 | 0.019 | 0.007 | 0.011 | 1.019 | 1.9 |
| | 1 | 0.140 | 0.011 | < 0.0001 | 1.151 | 15.1 |
| 7 | 0 | 0.030 | 0.009 | 0.001 | 1.030 | 3.0 |
| | 1 | 0.149 | 0.013 | < 0.0001 | 1.160 | 16.0 |
| 8 | 0 | 0.019 | 0.007 | 0.010 | 1.019 | 1.9 |
| | 1 | 0.132 | 0.011 | < 0.0001 | 1.141 | 14.1 |
| All | 0 | 0.019 | 0.003 | < 0.0001 | 1.019 | 1.9 |
| | 1 | 0.128 | 0.004 | < 0.0001 | 1.136 | 13.6 |

**b—in the treatment-groups vs. comparison-groups of drivers**

| Treatment type | *Odds ratio estimate*, in logarithmic-scale | St. Error | Adj P (Holm) | Exp(*Odds ratio estimate*) | Reduction in accident indicator between before and after periods, in treatment-group vs. comparison-group, % |
|---|---|---|---|---|---|
| 1 | 0.102 | 0.005 | < 0.0001 | 1.107 | 10.7 |
| 2 | 0.111 | 0.010 | < 0.0001 | 1.118 | 11.8 |
| 3 | 0.125 | 0.012 | < 0.0001 | 1.133 | 13.3 |
| 4 | 0.094 | 0.010 | < 0.0001 | 1.099 | 9.9 |
| 5 | 0.084 | 0.006 | < 0.0001 | 1.088 | 8.8 |
| 6 | 0.121 | 0.013 | < 0.0001 | 1.129 | 12.9 |
| 7 | 0.119 | 0.015 | < 0.0001 | 1.126 | 12.6 |
| 8 | 0.112 | 0.013 | < 0.0001 | 1.119 | 11.9 |
| All | 0.109 | 0.005 | < 0.0001 | 1.115 | 11.5 |

*Accident rate per 1,000 days

The study findings showed that the DPS did have impacts on committing traffic offences and drivers' involvement in road accidents. Following the implementation of DPS corrective measures, substantial and significant reductions were found in the violation rates as well as significant reductions in accident rates among the offending drivers. During the three-year period after the measures' implementation, as opposed to three-years before, the decrease in the commission of violations (with demerit points) was as high as 70%, and simultaneously, there was also a decrease in accident involvement indicators, at a level of 1% for severe accidents and of 11% for total injury accidents. In addition, a more prominent effect of the DPS on accident involvement was found for drivers who were treated in the year (2006) that was followed by the most extensive application of

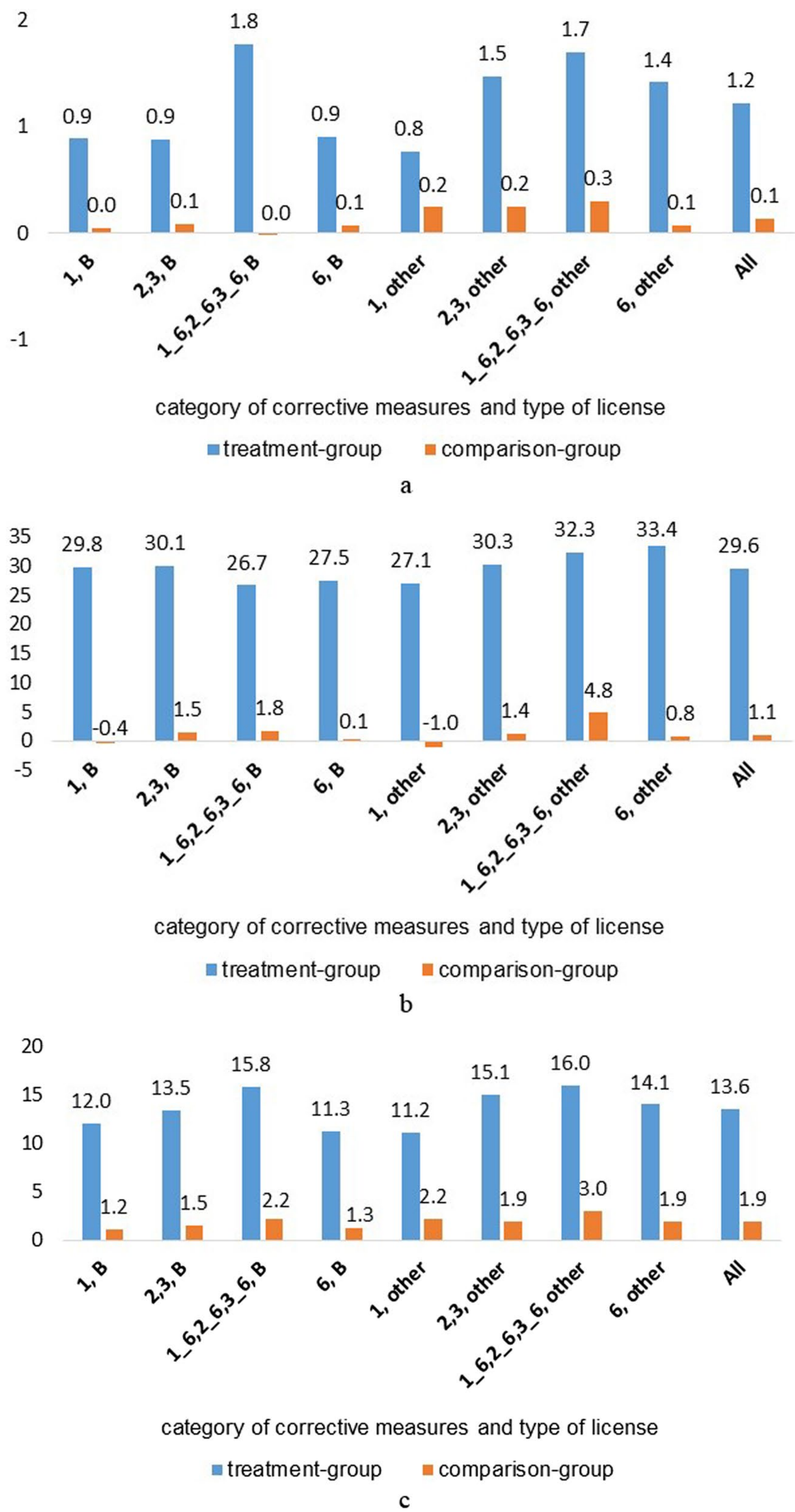


**Fig. 4** Percent of reduction in accident indicators, in the after vs. before period, among drivers who passed the DPS corrective measures and comparison-group drivers, by categories of corrective measure and type of license: **a** - in severe accidents; **b** - in injury accidents, when DPS measures were applied in 2006; **c** - in injury accidents, when DPS measures were applied after 2006. Notes: B – drivers with B-license (private cars); other – professional drivers (with other license types)

the corrective measures—a 28% decrease in injury accidents' rate. It is worth mentioning that all the reported effects were estimated having controlled for background drivers' characteristics, such as age-group and type of the city of residence (in terms of size and leading population groups). The magnitudes of the DPS effects observed in Israel were comparable with some previous studies [1, 3, 5, 8, 36], yet the evaluation framework was different as we indicated above.

The current study findings contribute to the previous international range of DPS safety estimates [9, 22, 39], with a particular focus on a DPS which was introduced over a long time-period – the case for which safety estimates were not explicitly available in the previous literature. The study revealed that even in the case of a non-uniform operation of the DPS, it produces positive impacts on traffic behaviors and accident involvement of the drivers who passed the corrective measures. Moreover, the study suggested an alternative evaluation framework for estimating DPS safety impacts when the traditional macro-analysis of changes in accidents or road-user behaviors in a region is less applicable as it can be subject to uncontrolled confounders. In addition, the study provided safety estimates associated with specific corrective measures, within the DPS, whereas such detailed estimates were generally missing in previous evaluation research of DPS implementation [2, 3, 8, 9, 12, 33, 36].

In this study, positive impacts of the DPS corrective measures on traffic violations and accident involvement, were found among drivers of private cars and professional drivers, while the effects in both cases were reasonably close. Thus, the study findings support the DPS implementation for all driver populations in the country as is defined by the law [44]. The DPS effects, in this study, were observed in the three-year period following the corrective measures' execution that was longer than the periods commonly monitored by previous research [9, 22].

In the international literature, different findings can be seen regarding the safety impacts of corrective measures. For example, previous research was inconsistent as to the impacts of driving improvement courses [13, 15, 19, 34], and generally reported stronger impacts of license suspension than other measures [31, 32, 34]. In contrast, the current study findings showed that all the DPS corrective means: basic course, advanced courses, license suspension, and their combinations, were effective and associated with reductions in traffic violations and accident involvement by drivers. Regarding violations, greater impacts were exhibited for driving improvement courses, while repeated basic course and measures' combination including a license suspension were less effective; although, all the types of corrective measures produced remarkable reductions in drivers' violation rates, ranging in 65%-80%. Concerning drivers' involvement in accidents, slightly higher impacts were observed for combinations of courses with license suspension, among the private and professional drivers, as well as for license suspension (alone) and an obligatory advanced course among the professional drivers. However, in general, the extent of decrease was fairly similar for all the types of measures, ranging from 1%-2% for severe accidents and from 9%-13% for total accidents.

The study did not estimate the impacts of "license revocation", the heaviest penalty measure in the current DPS (see Sec.3), since the treated drivers sample was insufficient for the analysis. This issue should be explored by future research as it probably has a potential to demonstrate stronger differences between the effects of various corrective measures.

## 6 Conclusions

Demerit points systems have been introduced as tools for improving road safety in the country [16, 17, 21, 22, 39]. This study examined the impacts of the DPS in Israel on committing traffic offenses and accident involvement of drivers, based on the national files of the Licensing Authority and a complementary accident file from the CBS. The models developed in the study enabled to evaluate changes in violation rates and accident rates of the offending drivers, after passing the DPS corrective measures, related to the before period, and having accounted for changes occurred in the comparison-groups of drivers. The study found that the DPS measures were effective in reducing the traffic violations committed by the drivers and their involvement in road accidents, while the results were consistent across various groups of drivers by the type of license and the corrective measures applied.

As expected, the DPS impacts on violation rates were more tangible than on accident involvement rates, but in both cases, the effects were significant indicating evident positive impact of the DPS. In this sense, the study provided new insights as to the DPS impacts on road safety in the local context, since this topic was not evaluated in the past, and also contributed to the range of international estimates of DPS effects [1–3, 5, 8, 9, 12, 18, 42].

The study results support the continued use of DPS in Israel, to improve drivers' behaviors and road safety. Being aware of the long period of the (revised) system's introduction and the unstable level of police enforcement during the study period, it is advisable to conduct a further evaluation of the DPS in the future.

Unlike previous research [15, 31, 32, 34], the study did not ascertain essential differences in the impacts of various DPS corrective measures, under the local conditions, thus more detailed examinations on the topic would be useful in future research. Furthermore, the quality of the DPS corrective measures such as basic and advanced driving improvement courses should be inspected, to improve the perceived impacts of the DPS among drivers, as well [28, 35, 39].

As the DPS was shown to reduce the violation rates and accident involvement of the treated drivers, it can contribute to the national road safety program. However, to increase its positive impacts on road safety, at the national level, the DPS should function effectively, without internal delays, that were observed in the current study, and be supported by stable police enforcement and publicity efforts, as suggested by international research [22, 39, 42].

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12544-023-00613-1.

**Additional file 1.** Models developed in the study, with their fit statistics.


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#### Author contributions
VG was a major contributor in designing the work, managing the study performance, interpreting data and findings, and writing the manuscript. AK prepared the data for analyses. ED developed the study models. WE and SH contributed in designing the work and interpreting the results. All authors read and contributed to writing the draft and approved the final manuscript.


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#### Availability of data and materials
The driver, violation and accident data used in this study were solely with permission for the current study and are not publicly available. The outputs of the models developed in the study are provided in the Additional file 1.

## Declarations

#### Competing interests
The authors declare that they have no competing interests.


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