

Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.



This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

<http://www.elsevier.com/copyright>



Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Effects of Pay-As-You-Drive vehicle insurance on young drivers' speed choice: Results of a Dutch field experiment

J.W. Bolderdijk^{a,*}, J. Knockaert^b, E.M. Steg^a, E.T. Verhoef^b^a Faculty of Behavioral and Social Sciences, University of Groningen, Grote Kruisstraat 2/1, The Netherlands^b Department of Spatial Economics, VU University Amsterdam, De Boelelaan 1105, Amsterdam, The Netherlands

ARTICLE INFO

Article history:

Received 25 March 2010
 Received in revised form
 23 December 2010
 Accepted 26 December 2010

Keywords:

Speeding
 Driving behavior
 Incentives
 GPS
 Pay-As-You-Drive
 Insurance

ABSTRACT

Speeding is an important cause for young drivers' involvement in traffic accidents. A reduction in driving speeds of this group could result in fewer accidents. One way of reducing driving speed is offering explicit financial incentives. In collaboration with five Dutch car insurance companies, we tested the effects of a Pay-As-You-Drive insurance fee on driving speed. A group of young drivers could save money on their monthly insurance fee by keeping the speed limit. Driving speed was monitored through GPS technology during one year. Analyses showed that, relative to pre- and post-measurement, as well as a control group, the introduction of a Pay-As-You-Drive insurance fee significantly reduced speed violations of young drivers.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Worldwide, across all age groups road traffic accidents currently account for 1.27 millions deaths a year (World Health Organization, 2004). Furthermore, traffic accidents constitute the second leading cause of death among people in the age of 20 to 24 years, right after HIV/AIDS (Toroyan and Peden, 2007). Young drivers are strongly overrepresented in road accident statistics. In the Netherlands, young adults (aged 18–24) make up 8% of the driving population, but are involved in 22% of all severe traffic accidents. This means that per kilometer travelled, young adults in the Netherlands are 5.5 times as likely to be involved in a severe traffic accident as older adults (Schoon and Schreuders, 2003). The differences in accident involvement are often attributed to specific characteristics of young adults. For example young drivers, compared to older drivers, have been found to have a more positive attitude towards taking risks, display stronger motives for risky driving (Hatfield and Fernandes, 2009), and tend to drive at higher speeds (Boyce and Geller, 2002).

Vehicle speed is commonly seen as the most important determinant of crash risk (Salusjärvi, 1981), and crash severity (Jokscha, 1993; OECD/ECMT, 2006). Driving at higher speeds leaves less

time to respond to unexpected events and increases stopping time, thus decreasing the possibility to avoid accidents (Aarts and van Schagen, 2006). So, reducing the driving speed of young adults, and in particular the amount of time spent above the speed limit, holds the potential of dramatically reducing accidents, and saving lives. The current study aimed to test whether a new type of car insurance (Pay-As-You-Drive vehicle insurance) is effective in reducing speed violations of young adults. Before explaining the study setup, we will discuss the (dis-)advantages of Pay-As-You-Drive vehicle insurance as compared to current road safety interventions.

1.1. Current road safety interventions: speed enforcement tools

Traditional road safety interventions, such as safety belts, improved road design, and wider road lanes have had great success in lowering road deaths. However, there has been some argument that these measures have largely only reduced accident severity and have done little to address the human component of traffic accidents (Rothengatter, 2002). In particular, it is thought that some drivers, in response to the perceived safety gains of certain interventions, drive in a fashion that may reduce the potential safety gains created by the intervention (Wilde, 1986; Jackson and Blackman, 1994; Lewis-Evans and Charlton, 2006).

In a contentious example of this viewpoint, called Risk Homeostasis Theory (RHT), it has been argued that individuals have a target level of risk at which they like to operate, and they will change their behavior to attempt to maintain this target risk level

* Corresponding author. Tel.: +31 50 363 6239; fax: +31 50 363 6304.

E-mail addresses: j.w.bolderdijk@rug.nl (J.W. Bolderdijk), jknockaert@feweb.vu.nl (J. Knockaert), e.m.steg@rug.nl (E.M. Steg), everhoef@feweb.vu.nl (E.T. Verhoef).

(Wilde, 1986). Wilde (1988) goes as far as claiming that the only way to achieve long lasting reductions in accidents is for road safety interventions to reduce drivers' target level of risk, otherwise no net safety benefit will be achieved. The target level of risk, according to RHT, is determined by the perceived costs and benefits of risky and cautious behavioral options. Financial consequences, both negative (penalties) and positive (rewards) can be used to provide additional costs and benefits to risky and cautious behavioral options, and thus may decrease drivers' target level of risk, which should reduce risk taking behavior (Wilde and Murdoch, 1982).

Speed enforcement tools can provide such financial consequences. They typically impose penalties (fines) on risky behavior (rather than providing rewards for safe behavior). Research shows that interventions involving penalties (e.g. mobile radars and fixed cameras providing fines to speed violators) indeed can effectively deter speeding in the general population (e.g. Goldenbeld and van Schagen, 2005; Shin et al., 2009), and thus reduce road crashes. Unfortunately, the deterring effects of such interventions are often only local, in that speeding is only reduced in the proximity of areas where driving speed is being monitored (Hauer et al., 1982).

Practical limitations prohibit current enforcement tools (e.g. fixed cameras and mobile radars) to be present on every possible road. Accordingly, drivers assess the likelihood of incurring a penalty for speeding at any given road to be (very) low (De Waard and Rooijers, 1992). Considering that financial speed enforcement tools are most effective when drivers' perceive the likelihood of being caught to be high, vehicle speeds would ideally be monitored constantly, across all roads, allowing financial penalties to be imposed on all, rather than just a subset of speed violations. Advanced speed monitoring systems provide this possibility (OECD/ECMT, 2006). GPS technology, combined with information on local speed limits, allows for the automatic and continuous monitoring of vehicle speed and by comparing current vehicle speeds with local speed limits, one can establish whether and where speed violations occurred. Automatically detected violations could then be translated into financial penalties to drivers. Such a system is potentially very effective in reducing overall speeding; it imposes consistent penalties on risky behavior. However, advanced speed monitoring systems do have one particularly large drawback preventing their implementation; they are hardly acceptable to the general public, as people are likely to oppose a mandatory GPS device in cars that penalizes them for every speed violation they commit (OECD/ECMT, 2006). However, Pay-As-You-Drive (PAYD hereafter) vehicle insurance, a recent development in automobile insurance, may tackle this problem in an effective, yet acceptable way.

1.2. Pay-As-You-Drive vehicle insurance

PAYD entails that insurance premiums are directly based on the driving behavior of policyholders (Litman, 2005). Generally, PAYD ties the level of insurance premium to the risk level associated with driving behavior of the policyholder (e.g. increased mileage and speeding are associated with increased crash risks, and thus will result in a higher insurance premium). This system of variable premiums poses an alternative to the current system of fixed insurance premiums exclusively based on proxies for risk such as age and gender, rather than on the actual driving behavior of policyholders.

In addition to increasing actuarial accuracy (risks are better reflected in premium, cf. Litman, 2005), PAYD might lead to a change in the driving behavior of policyholders. Because risk taking is reflected in individual insurance premiums, the system provides additional financial consequences associated with cautious and risky driving, in that by changing their driving behavior, policyholders can save money on their insurance. PAYD, in combination with GPS devices in policy holders' cars, allows for the variabilisation of

insurance premiums based on a multitude of risk factors, including driving volume (mileage) and style (e.g. speed, acceleration, deceleration), as well as other factors (e.g. time of driving). As a tool for behavior change, PAYD may help in tackling major road-safety risks, such as speed violations and nighttime driving (Sivak et al., 2007), and may yield additional societal benefits through reduced mileage, such as lower vehicle emissions and reduced congestion. PAYD might be especially effective in changing the driving behavior of young drivers as traditionally young drivers pay relatively high premiums, and variabilisation of their premiums could therefore lead to relatively large financial incentives.

As a tool for reducing speed, PAYD (in combination with GPS technology) offers a number of advantages over more conventional speed enforcement tools. Since PAYD means that premiums are directly tied to logged vehicle speeds, policyholders face a continuous and non-randomized financial incentive to keep the speed limit. Thus, as opposed to conventional speed enforcement tools, reduced speeding would not be limited to specific locations. Additionally, the perceived risk of detection, which is commonly seen as the crucial factor in speed enforcement (see De Waard and Rooijers, 1994) is very high with GPS-based monitoring, as all speed violations can have financial consequences. Moreover, PAYD can be used to provide financial rewards (reduced premium) for cautious behavior (keeping the speed limit), besides imposing financial penalties for risky behavior. People generally rate rewards as more acceptable tools for behavior change than penalties (Wit and Wilke, 1990), which suggest that PAYD will probably be rated as more acceptable than advanced speed monitoring systems that typically only involve penalties (OECD/ECMT, 2006).

The current study aims to test how PAYD, in combination with in-car GPS devices, affects driving behavior in a randomized controlled field trial. Specifically, we aimed to test to what extent a financial incentive (a reward in the form of a discount on policyholders' insurance premium) in combination with feedback affects the actual driving speed of young drivers. The literature suggests that speed is one of the most important predictors of crash risk (Aarts and van Schagen, 2006), therefore our primary interest was testing the effects of PAYD on speeding, which is driving above the posted speed limits. However, the field experiment also included a financial incentive for participants to reduce their mileage and avoid driving on weekend nighttime hours, as increased mileage and driving at night during weekends have been associated with increased accident risk (Sivak et al., 2007).

2. Method

2.1. Participants

In January 2007, we sent a letter with the request to fill out an online questionnaire on PAYD (duration 20 min) to approximately 6000 policyholders from five Dutch insurance companies (all policyholders were younger than 30 years). By filling out the questionnaire, participants were eligible to win a car navigation system. By July 2007, 706 policyholders had completed the online questionnaire. In the last part of the questionnaire, participants indicated whether they were interested in participating in a field experiment on PAYD. A substantial proportion of the people who filled out the questionnaire ($n=337$) volunteered. However, because not all volunteers could be accommodated in the field experiment, a random selection of 228 people were eventually invited to participate.

In the time between the participant selection and the installation and testing of the GPS device, some participants withdrew. Additionally, some participants were excluded from the analyses due to missing data (e.g. their GPS device did not work properly

or was removed before the end of the experiment). By the end of the experiment (July 2008), we could establish the prevalence of speeding behavior throughout all phases of the experiment for 141 participants. The participants who dropped out ($n = 87$) did not differ in age, car size, income, gender, and intention to speed from the final set of participants ($n = 141$), but did report a somewhat lower yearly mileage. Self-reported mean yearly mileage of the final set of participants was 13,985 km, which is comparable to the 2007 Dutch average of 13,877 km (Centraal Bureau voor de Statistiek, 2009a). In July 2007, the mean age of participants was 24.4 years ($SD = 2.2$), and on average participants had possessed a driver's license for 4.5 years ($SD = 2.4$). Men (60%) were slightly overrepresented in the sample. The majority of participants worked fulltime (69.3%), and 30.7% were otherwise engaged (studying, part-time employment). Net monthly income levels were somewhat higher than the average income of Dutch young adults, with 25.7% of the sample earning less than 1000 Euros net per month, 46.2% earning between 1000 Euros to 1500 Euros net per month, 24.3% earning between 1500 and 2000 Euros net per month, and 3.7% earning more than 2000 Euros net per month (Centraal Bureau voor de Statistiek, 2009b).

2.2. Design and procedure

The field experiment ran from November 2007 until June 2008. Prior to the start of the field experiment, participants' cars were equipped with GPS devices. These GPS devices allowed for the monitoring of where participants were driving, what speed they were driving at and at what time, and how many kilometers they were travelling. Participants were randomly assigned to be either in incentive or control groups. The experiment comprised four phases, pre-measurement, intervention phase 1, intervention phase 2, and post-measurement, each phase lasting two months. During pre-measurement (November–December 2008) and post-measurement (May–June 2008), participants' driving behavior was monitored, but had no financial consequences. During the intervention phases, participants in the incentive group could earn a reward for adapting their driving behavior (a discount on their insurance premium of maximally 50 Euros per month), and received feedback on their driving behavior. Participants in the control group did not receive an incentive and feedback. The intervention period was divided into two phases, each lasting two months (intervention phase 1: January–February 2008, intervention phase 2: April–May 2008). This setup allowed us to compare driving behavior during four phases of equal length in the analyses (pre-measurement, intervention phase 1, intervention phase 2, and post-measurement).

The monthly 50 Euros discount was divided into three components: 30 Euros was designated as a reward for keeping the speed limit,¹ 15 Euros for reduced mileage, and 5 Euros for avoiding driving during weekend nighttime hours.² So, the maximum discount participants could earn during the two intervention phases was 200 Euros. Based on loss aversion (Tversky and Kahneman, 1981), we reasoned that financial losses should have more impact on behavior than equivalent financial gains. So communicating the reward

drivers are foregoing (losing) by driving unsafely, may be a more effective frame than communicating the reward drivers are receiving (gaining) by driving safely. Accordingly, in the intervention phases, we used two ways to communicate how much of discount participants in the incentive group had earned. Participants in the gain framed incentive group ($n = 50$) were told that they started each month with 0 Euros, and could *gain* up to 50 Euros discount if they drove safely (which entailed keeping the speed limit, avoiding driving during on weekend nighttime hours, and reducing mileage). Conversely, participants in the loss framed incentive group ($n = 50$) were told that they started each month with 50 Euros discount, and could *lose* up to 50 Euros a month if they failed to drive safely.

Participants in the incentive groups could track their performance during the intervention phases (from January to April 2008) by logging in to a personalized website (www.savedriver.nl). The website provided detailed feedback on speed violations, mileage, and nighttime driving, and showed, by default, how much discount the particular participant would receive at the end of the month if they continued the driving behavior of the previous week. Specifically, participants in the gain framed incentive group saw a graph that denoted how much discount they would gain, and participants in the loss framed incentive group saw a graph that denoted how much discount they would lose.

Payments were made via bank transfer. The first of four monthly payments were made in March of 2008. Subsequent monthly payments were made in March, April and May 2008. A control group was used to assess the impact of extraneous variables on driving behavior. Right before the start of the first intervention period, participants in the control ($n = 41$) group were told that they would *always* receive the maximum discount of 200 Euros at the end of the experiment, irrespective of their driving behavior. They did not receive feedback on their driving behavior, and were paid 200 Euros during post-measurement.

2.3. Data analysis

During the field experiment, in-vehicle GPS devices logged X and Y coordinates every 100 m. On some occasions (e.g. in case of a loss of GPS signal, for instance due to driving through a tunnel), the GPS device logged on longer intervals (that is, less often than every 100 m). These observations (which amount to 23.4% of the total distance travelled) were removed from the analyses, as vehicle speed for these longer intervals could not be reliably determined. The occurrence of speed violations was established by matching vehicle location and vehicle speed to a map with local speed limits. Data was recorded on all types of roads, but analyses were limited to the most common road types in the Netherlands, with speed limits of 30, 50, 80, 100 and 120 km/h, respectively, and to observations for which local speed limit information was available (98.9%). Many Dutch roads tend to be congested around peak hours on weekday. During congestion, participants' would have to deal with other vehicles ahead of them, which would prevent them from freely choosing their speed. This means that speed choice is more likely to be under volitional control during off-peak hours than during peak hours.³ Driving behavior recorded on peak hours (from 7 to 9 am and from 4 to 7 pm on weekdays) was therefore excluded from our analyses.

The percentage of total distance travelled at 6% or more above the local speed limit ('percentage of speeding') was used as the main dependent variable in our analyses. Violations of less than 6% were excluded from this definition, based on the assumption that such violations are often non-volitional and therefore most likely

¹ Based on the average speed over fixed intervals, participants received a specific number of penalty points. The more penalty points participants collected, the lower their monthly reward for keeping to the speed limit. Excessive speeding (driving over 20% of the speed limit), as well as speeding during weekend nighttime hours are associated with higher crash risks, and resulted extra penalty points. Minor speed violations (less than 6% in excess of the posted speed limit) were not penalized.

² These components were not fixed, but were calibrated to be 30, 15 and 5 Euros, respectively. So, in theory, participants could forfeit more than 30, 15 and 5 rewards for speeding, increasing mileage and driving during weekend nighttime hours, respectively. The monthly total rewards were limited to a maximum of 50 Euros. In January 2008, 1 Euro = \$1.46.

³ Analyses show that participants indeed speed less on peak than on off-peak hours.

not influenced by a financial incentive and feedback. Furthermore, small thresholds are quite common in speed enforcement. Dutch police, for instance, only issue speeding tickets at 80 km/h roads for violations of 7 km/h or more over the speed limit (Goldenbeld and van Schagen, 2005).

For each of the four phases of the field experiment, the percentage of speeding was calculated based on the weekly distance travelled at a speed 6% over the speed limit across all five road types (30, 50, 80, 100 and 120 km/h). Percentage speeding of the five road types were weighted by distance, and averaged across road types. The resulting variable represents an indicator of volitional speeding across all road types, and was used as a dependent variable in our analysis of the effect of PAYD on overall speeding. During off-peak periods, local speed limits were violated by 6% or more during 19.1% of the distance travelled. This figure is in line with previous literature that used GPS devices to measure vehicle speeds (Hultkrantz and Lindberg, 2003). Because the variable percentage of speeding was not normally distributed the natural logarithm of the scores was used in the analyses.

3. Results

3.1. Effects of PAYD on overall percentage of speeding

No effect of gain/loss incentive framing on speeding was found, as a multivariate test showed that the percentage of speeding did not differ for loss and gain framed incentive groups during any phase of the experiment, $F(4, 95) = 1.22$, n.s. Thus, the data from the loss ($n = 50$) and gain framed incentive groups ($n = 50$) were collapsed into a single incentive group ($n = 100$). This allowed us to directly compare the behavior of drivers who were exposed to PAYD (incentive group, $n = 100$) to the behavior of drivers who were not exposed to PAYD (the control group, $n = 41$) in further analyses.

A mixed design was used, with the four phases of the experiment (pre-measurement, intervention phase 1, intervention phase 2, and post-measurement) as the within-subjects variable, and experimental condition (incentive vs. control group) as the between-subjects variable. Mauchly's test of sphericity was significant, so Huynh-Feldt tests were used. A main effect of phase appeared, $F(2.72, 378.49) = 5.45$, $p < .01$, signaling that, across groups, percentage speeding depended on phase. The overall percentage of speeding increased from pre-measurement to post-measurement for both the incentive and control group (see Fig. 1). More importantly, a significant phase*condition interaction appeared, $F(2.65, 378.49) = 6.04$, $p < .001$, which indicates that the effect of condition depended on phase. Planned contrasts showed that percentage of speeding of participants in the incentive group decreased after the financial incentive was introduced (pre-measurement = 18.6%, intervention phase 1 = 17.7%, $M_{\text{difference}} = -.9\%$, $F(1,99) = 13.82$, $p < .001$, $\eta_p^2 = .122$), remained at the same level during the intervention (intervention phase 1 = 17.7%, intervention phase 2 = 17.6%, $M_{\text{difference}} = -.1\%$, n.s.), and increased after the financial incentive was removed (intervention phase 2 = 17.6%, post-measurement = 20.5%, $M_{\text{difference}} = +2.9\%$, $F(1,99) = 22.77$, $p < .001$, $\eta_p^2 = .187$). Conversely, the percentage speeding of participants in the control group consistently increased as the experiment progressed (pre-measurement = 17.9%, intervention phase 1 = 19.0%, intervention phase 2 = 19.7%, post-measurement = 19.7%, $M_{\text{pre-post measurement}} = +1.8\%$, $F(1,40) = 5.29$, $p < .05$, $\eta_p^2 = .177$, other contrasts were not significant). In sum, the incentive group reduced speeding after the financial incentive was introduced, and increased speeding when the financial incentive was removed. This pattern of results is unlikely to be caused by extraneous variables, as the control group does not display a parallel drop in speeding during the intervention period.

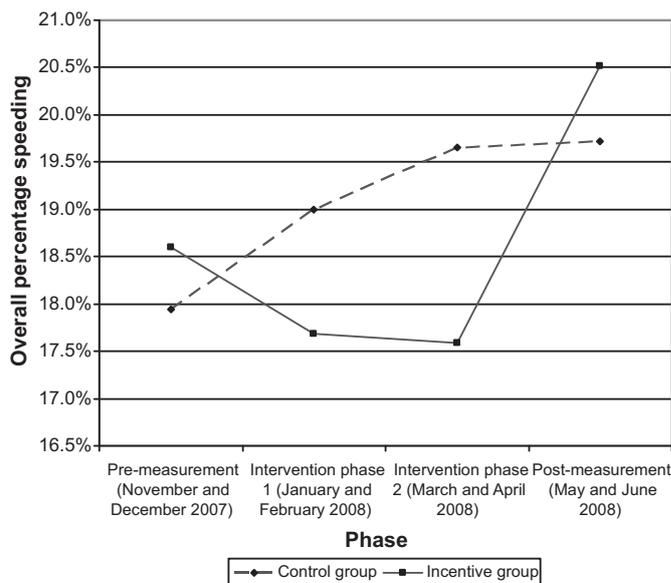


Fig. 1. Overall percentage speeding for incentive and control groups.

These results therefore suggest that PAYD reduced overall speeding.

3.2. Effects of PAYD on the percentage of speeding on different road types

Additionally, we compared the percentage of speeding in the incentive group during the unrewarded periods (pre- and post-measurement) with the percentage of speeding during the rewarded periods (the two intervention phases) for all five road types separately. This allowed us to directly test whether the effect of PAYD on speeding differs for different road types. The means and standard errors are displayed in Fig. 2.

A repeated measures analysis of variance was used, with period (rewarded vs. unrewarded) and road type (30, 50, 80, 100 and 120 km/h) as within-subjects variables. Mauchly's test of sphericity was significant, and Huynh-Feldt tests were conducted. A main effect of period appeared, $F(1, 90) = 16.40$, $p < .001$, as percentage of speeding was lower during the rewarded (intervention phases) than during the unrewarded periods (pre- and post-measurement). Additionally, a main effect of road type appeared, $F(2.907, 261.598) = 142.90$, $p < .001$, the percentage of speeding was higher on roads with lower speed limits. Whereas participants exceeded the speed limit by 6% or more for almost half of the distance travelled (42%) on 30 km/h roads, speed limits

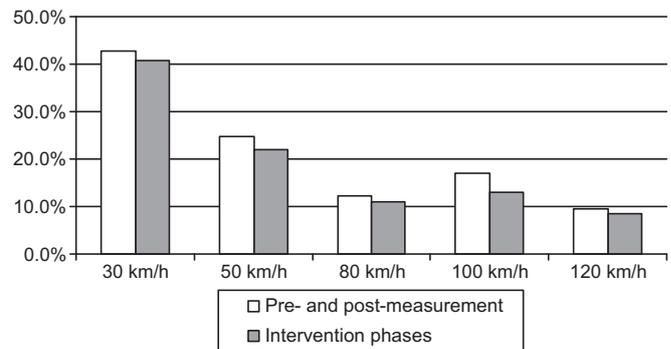


Fig. 2. Overall percentage speeding for the incentive group across different road types.

were only exceeded by 6% or more for just 10% of the distance travelled at 120 km/h roads. Moreover, a (marginally) significant period*road type interaction appeared, $F(3.149, 283.450)=2.14$, $p=.09$, which suggests that the difference in percentage speeding under rewarded versus unrewarded periods depends on road type. As can be seen from Fig. 2, it appears that PAYD exerts the strongest effects on 50, 80 and 100 km/h roads.

3.3. Effects of PAYD on mileage and nighttime driving

Our main interest was in testing whether the financial incentive would influence speeding, but we also tested whether PAYD affected total distance travelled and distance driven on weekend nights. Contrary to other PAYD pilots (e.g. Buxbaum, 2006), we were not able to demonstrate PAYD resulted in reductions in mileage or in reductions in driving on weekend nighttime hours. Therefore, no further consideration will be given to the effects of PAYD on mileage and distance travelled during weekend nighttime hours.

4. Discussion and conclusion

4.1. The scope of PAYD as a tool for changing driver behavior

In a randomized controlled field experiment, PAYD resulted in modest, but significant reductions in speeding of young drivers. However, we could not demonstrate an effect of PAYD on travel volume (mileage and nighttime driving). Why was this the case? The obvious answer would be that participants thought that the largest part (30 Euros) of the monthly discount could be earned by keeping the speed limit, and only a smaller part (15 and 5 Euros) could be earned by reducing mileage and avoiding driving during weekend nighttime hours, respectively. In other words, participants may have seen more benefit in changing driving style (speeding) than in changing travel volume. Alternatively, one could argue that reducing travel volume also requires planning (Gärling and Schuitema, 2007), and may be experienced as more effortful and difficult than changing driving speed. In fact, when a small sample of participants was interviewed about their experiences with the experiment, most indicated that reducing mileage and avoiding nighttime driving was very difficult. Reduction of driving speed contrarily, does not require planning. So, it may be easier for drivers to change driving style than driving volume, which may help explain why we were able to demonstrate effects of PAYD on speed choice, but not on mileage and driving during weekend nighttime hours.

Although PAYD seems effective in reducing speeding across all road types, PAYD appears especially effective at reducing speed violations at 50, 80 and 100 km/h roads. So why is PAYD (somewhat) less effective at 30 and 120 km/h roads? As can be seen from Fig. 2, percentage speeding is very high at 30 km/h roads, and very low at 120 km/h roads. Thus, the limited effects of PAYD on speeding on these roads may be due to ceiling and floor effects, respectively. Speed violations, as defined by a 6% or more threshold, on 30 km/h are easily committed (a 6% speed violations entails driving over 31.8 km/h), and may therefore be likely to occur involuntary, irrespective of whether one is motivated to reduce speeds by a financial incentive. Similarly, speed violations of 6% or more are infrequent events at 120 km/h roads, and adding a financial incentive may not reduce speeding much further. Interestingly, accident statistics show that most fatal car accidents occur at undivided two-lane rural roads (Persaud et al., 2004), of which 80 and 100 km/h roads in the Netherlands are typical examples. As such, PAYD appears especially effective at roads where reduced speeding may result in relatively large safety gains.

4.2. Effects of being monitored

It can be seen from Fig. 1 that the percentage of speeding, both in the control and incentive group, increases between the pre and post-measurement phases. Moreover, the percentage of speeding in the control group consistently increased during all four phases of the experiment. This specific pattern of results may be attributed to seasonal changes (improving weather and traffic conditions) as pre-measurement took place during Winter (November–December), while post-measurement took place during Spring (May–June), in which driving conditions were more favorable (less precipitation and higher temperatures). Although this is a possibility, it does not explain why participants in the control group increased speeding *within* the winter season, that is, from November/December to January/February.

An increase in speeding under similar weather conditions may perhaps be explained by the fact that participants, both in the control and incentive group, were initially aware of the fact that their behavior was monitored via the GPS device (and adapted their behavior accordingly), but this awareness faded over time. From prior research (Nielsen and Jovicic, 2003), we know that monitoring driving behavior may have an impact on driving behavior by itself as the knowledge that one is being monitored might deter drivers from speeding, even when no financial consequences are present. The fact that people might change their behavior simply because they are being observed has been documented in other fields as well, and has been attributed to reputational concerns (e.g. Bateson et al., 2006). Thus, it seems plausible that, in addition to seasonal changes in weather and traffic conditions, increased speeding from pre- to post-measurement can be attributed to the fading awareness of being monitored.

4.3. Limitations

To our knowledge, the current study is the first to test the effects of PAYD on speeding in a randomized controlled field trial. As mentioned in the method section, GPS devices allow for a test of the effects of PAYD on actual speed choice, rather than speeding attitudes, intention, or self-reported behavior. However, the GPS devices did not always function perfectly (e.g. due to failing GPS signal in tunnels), so we faced some missing data in the dataset. Nevertheless, PAYD did significantly reduce speed violations, which suggests that, if anything, our results reflect a somewhat conservative test of the effect of PAYD on speeding.

Participants in the incentive group received both feedback and a monetary incentive. As such, one might reason that the pattern of results obtained in the incentive group might have also occurred without a financial incentive, and could be attributed to the presence of feedback. We however expect this possibility to be unlikely. First, feedback tends to be effective when presented frequently, and in close proximity to the target behavior (Fischer, 2008), which was not the case in our experiment. Second, considering the limited number of participants that actually visited the website (the majority of participants did not visit the website during the first intervention phase, let alone during later stages of the experiment), it seems unlikely that the presence of the website, by itself, can account for the pattern of results.

Finally, this study explicitly aimed to test the effects of PAYD among young drivers, as these drivers are associated with higher risk levels. We would welcome further research assessing whether PAYD would have similar positive effects of the driving behavior of other age groups.

4.4. Conclusions

As noted before, the awareness of being monitored may initially have reduced speeding, but, as time passed, this awareness faded, and speeding returned to its 'natural' level. As such, we reason that vehicle speeds during post-measurement are a better reflection of the speed at which participants would normally drive than speed levels during pre-measurement, where the GPS device had been recently installed and might have deterred participants from driving at their regular speeds.

Following this logic, the best possible estimation of the effect of PAYD on speeding might be reflected in the difference in speeding of the incentive group during the second intervention phase (March and April 2008) and after the incentive was taken away (post-measurement, May and June 2008). In other words, the financial incentive appears to have decreased the percentage of distance travelled during which drivers violated the speed limits by 6% or more from 20.5% to 17.6%. To put it differently, PAYD is estimated to have reduced volitional speeding by 14%, which roughly amounts to a reduction of 39.2 h per year for the average young driver.⁴ Although these numbers might not appear impressive, one should note that these numbers reflect reductions in actual speeding across all roads participants drove at. As such, the safety gains from PAYD could add significantly to those already made through the use of more conventional speed enforcement tools (e.g. speed cameras and mobile radars), especially as the effects of such tools on driving speed are typically limited to areas where enforcement is active. Also, small differences in driving speed are associated with large differences in crash risk (Elvik, 2006). A reduction of speeding by 5% may lead to as much as a 20% decrease of fatalities in road accidents (OECD/ECMT, 2006). Thus, we conclude that PAYD leads to modest, but relevant reductions in the driving speed of young adults, and thus may prove a valuable tool in reducing the crash risk of young drivers.

Acknowledgements

This research was made possible with the support of Transumo (TRANSition SUSTainable MOBility), a Dutch platform for companies, governments and knowledge institutes to cooperate in the development of knowledge in regard to sustainable mobility. We would also like to thank STOK (Telematics and Pay As You Drive solutions) their help with data collection, and Tom Postmes, Ben Lewis-Evans and Melvyn Hamstra for comments on an earlier draft of this paper.

References

- Aarts, H., van Schagen, I., 2006. Driving speed and the risk of road crashes: a review. *Accident Analysis & Prevention* 38, 215–224.
- Bateson, M., Nettle, D., Roberts, G., 2006. Cues of being watched enhance cooperation in a real-world setting. *Biology Letters* 2, 412–414.
- Boyce, T., Geller, E.S., 2002. An instrumented vehicle assessment of problem behavior and driving style: do younger males really take more risks? *Accident Analysis & Prevention* 34, 51–64.
- Buxbaum, J., 2006. Mileage-Based User Fee Demonstration Project: Pay-As-You-Drive Experimental Findings.
- Centraal Bureau voor de Statistiek, 2009a. Gemiddelde jaarkilometrage van personenauto's. Den Haag/Heerlen, CBS. Retrieved from www.cbs.nl.
- Centraal Bureau voor de Statistiek, 2009b. Inkomensverdeling huishoudens 2008. Den Haag/Heerlen, CBS. Retrieved from www.cbs.nl.
- De Waard, D., Rooijers, T., 1992. *Het effect van handhavingsactiviteiten op rijnsnelheid op autosnelwegen* Deel 1: Intensiteit, methodiek en afhandeling (Rep. No. VK 92-01). Verkeerskundig Studiecentrum Rijksuniversiteit Groningen, Groningen.
- De Waard, D., Rooijers, T., 1994. An experimental study to evaluate the effectiveness of different methods and intensities of law enforcement on driving speed on motorways. *Accident Analysis & Prevention* 26, 751–765.
- Elvik, R., 2006. Laws of accident causation. *Accident Analysis and Prevention* 38, 742–747.
- Fischer, C., 2008. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency* 1, 79–104.
- Gärling, T., Schuitema, G., 2007. Travel demand management targeting reduced private car use: effectiveness, public acceptability and political feasibility. *Journal of Social Issues* 63, 139–153.
- Goldenbeld, C., van Schagen, I., 2005. The effects of speed enforcement with mobile radar on speed and accidents: an evaluation study on rural roads in the Dutch province Friesland. *Accident Analysis & Prevention* 37, 1135–1144.
- Hatfield, J., Fernandes, R., 2009. The role of risk-propensity in the risky driving of younger drivers. *Accident Analysis & Prevention* 41, 25–35.
- Hauer, E., Ahlin, F.J., Bowser, J.S., 1982. Speed enforcement and speed choice. *Accident Analysis & Prevention* 14, 267–278.
- Hultkrantz, L., Lindberg, G., 2003. Intelligent economic speed adaption. In: Paper presented at the 10th International Conference on Travel Behavior Research, Lucerne, Switzerland.
- Jackson, J.S.H., Blackman, R., 1994. A driving-simulator test of Wilde's risk homeostasis theory. *Journal of Applied Psychology* 79, 950–958.
- Jochsch, H.C., 1993. Velocity change and fatality risk in a crash—a rule of thumb. *Accident Analysis and Prevention* 25, 103–104.
- Lewis-Evans, B., Charlton, S.G., 2006. Explicit and implicit processes in behavioral adaptation to road width. *Accident Analysis & Prevention* 38, 610–617.
- Litman, T., 2005. Pay-As-You-Drive vehicle insurance: converting vehicle insurance premiums into use-based charges. Retrieved from <http://www.vtpi.org/tdm/tdm79.htm> on the 23rd of June 2006.
- Nielsen, O.A., Jovicic, G., 2003. The AKTA road pricing experiment in Copenhagen. In: Paper presented at the 10th International Conference on Travel Behavior Research, Lucerne, Switzerland.
- OECD/ECMT, 2006. Speed Management. OECD Publishing, Paris.
- Persaud, B.N., Retting, R.A., Lyon, C.A., 2004. Crash reduction following installation of centerline rumble strips on rural two-lane roads. *Accident Analysis & Prevention* 36, 1073–1079.
- Rothengatter, T., 2002. Drivers' illusions—no more risk. *Transport Research Part F* 5, 249–258.
- Salusjärvi, M., 1981. Speed limits and traffic accidents in Finland. In: Proceedings of the OECD Symposium on the Effects of Speed Limits on Traffic Accidents & Transport Energy Use.
- Schoon, C. C., & Schreuders, M., 2003. De verkeersonveiligheid in Nederland tot en met 2003 (Rep. No. R-2005-15). Leidschendam: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.
- Shin, K., Washington, S.P., van Schalkwyk, I., 2009. Evaluation of the Scottsdale Loop 101 automated speed enforcement demonstration program. *Accident Analysis and Prevention* 41, 393–403.
- Sivak, M., Luoma, J., Flannagan, M.J., Bingham, C.R., Eby, D.W., Shope, J.T., 2007. Traffic safety in the U.S.: re-examining major opportunities. *Journal of Safety Research* 38, 337–355.
- Toroyan, T., Peden, M., 2007. Youth and Road Safety. World Health Organization, Geneva.
- Tversky, A., Kahneman, D., 1981. The framing of decisions and the psychology of choice. *Science* 211, 453–458.
- Wilde, G.J., 1986. Beyond the concept of risk homeostasis: suggestions for research and application towards the prevention of accidents and lifestyle-related disease. *Accident Analysis & Prevention* 18, 377–401.
- Wilde, G., 1988. Risk homeostasis theory and traffic accidents: propositions, deductions and discussion of dissension in recent reactions. *Ergonomics* 31, 441–468.
- Wilde, G.J., Murdoch, P.A., 1982. Incentive systems for accident-free and violation-free driving in the general population. *Ergonomics* 25, 879–890.
- Wit, A., Wilke, H., 1990. The presentation of rewards and punishments in a simulated social dilemma. *Social Behavior* 5, 231–245.
- World Health Organization, 2004. Fact sheet: the top ten causes of death. Retrieved from www.who.int.

⁴ Assuming an average speed of 50 km/h across all roads, and 14,000 km yearly mileage.