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The impact of immediate or delayed feedback on driving behaviour in a simulated Pay-As-You-Drive system

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ABSTRACT

Pay-As-You-Drive (PAYD) insurance links an individual's driving behaviour to the insurance fee that they pay, making car insurance more actuarially accurate. The best known PAYD insurance format is purely mileage based and is estimated to reduce accidents by about 15% (Litman, 2011). However, these benefits could be further enhanced by incorporating a wider range of driving behaviours, such as lateral and longitudinal accelerations and speeding behaviour, thereby stimulating not only a safe but also an eco-friendly driving style. Currently, feedback on rewards and driver behaviour is mostly provided through a web-based interface, which is presented temporally separated from driving. However, providing immediate feedback within the vehicle itself could elicit more effect. To investigate this hypothesis, two groups of 20 participants drove with a behavioural based PAYD system in a driving simulator and were provided with either delayed feedback through a website, or immediate feedback through an in-car interface, allowing them to earn up to €6 extra. To be clear, every participant in the web group did actually view their feedback during the one week between sessions. Results indicate clear driving behaviour improvements for both PAYD groups as compared to baseline rides and an equal sized control group. After both PAYD groups had received feedback, the initial advantage of the in-car group was reduced substantially. Taken together with usability ratings and driving behaviours in specific situations these results show a moderate advantage of using immediate in-car feedback. However, the study also showed that under conditions of feedback certainty, the effectiveness of delayed feedback approaches that of immediate feedback as compared to a naïve control group.

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1. Introduction

Pay-As-You-Drive insurance (PAYD), where insurance customers are charged directly for when, where, and how they drive, is now possible thanks to modern information and communication technology. PAYD addresses many problems with traditional insurance in that it is more fair, and transparently charges users for their own driving behaviour, rather than the behaviours of an aggregate group, and lessens the financial impacts of insurance on lower socioeconomic groups in particular (Adkins, 2004; Litman, 2005, 2011; Bordoff and Noel, 2008). Indeed, some estimates of PAYD in the USA have suggested that if mileage based PAYD was

implemented, where you pay insurance based on the distance you drive, two thirds of households would benefit with savings of around \$270 USD per car per year (Bordoff and Noel, 2008; Litman, 2011).

The potential benefits of PAYD insurance are not only limited to individual insurance customers. Rather, it is estimated that PAYD would also have significant societal impacts, including possible reductions in mileage of up to 8–12% (Harvey and Deakin, 1998; Adkins, 2004; Balcombe et al., 2004; Litman, 2005, 2011; Bordoff and Noel, 2008). Such reductions in mileage could be associated with total accident reductions of 12–18% (Litman, 2011). Furthermore, it is estimated that even an 8% reduction in mileage would reduce carbon dioxide emissions by 2% and petrol consumption by 4%. This reduction in petrol consumption would be equivalent to the effect of a \$1 USD per gallon increase in the price of petrol (Bordoff and Noel, 2008).

The above estimates are mostly based on economic and transport models and therefore may or may not completely reflect reality. Assessing the real world impacts of PAYD insurance, however, is difficult as PAYD has not been widely adopted and data

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on its effectiveness are obviously commercially sensitive. A few research projects have been carried out and have tended to find significant positive impacts of PAYD on driving, yet these impacts have been somewhat more modest than those predicted by modellers. Reported effects have included reductions in speeding in the case of Pay-As-You-Speed additions to PAYD insurance (Mazureck and van Hattem, 2006; Bolderdijk et al., 2011; Greaves and Fifer, 2011), and reductions in mileage under both Pay-As-You-Speed (Greaves and Fifer, 2011) and mileage based PAYD conditions (Buxbaum, 2006).

As already hinted at above, there can be many types of PAYD insurance. Ranging from pre-paid options, where customers pre-purchase a certain number of miles and are then charged based on additional mileage driven, to full behaviour based telematics PAYD insurance, where drivers can be rewarded or penalised based on not only how much they drive, but also on where, when, and how they drive (Litman, 2005, 2011; Bordoff and Noel, 2008). This, later, behaviour based PAYD could be hypothesised to be more effective than simple mileage based PAYD due to its capability to provide richer feedback on driver behaviour that is currently sorely lacking in the road environment (Thorndike, 1911; Watson, 1917; Näätänen and Summala, 1974; Skinner, 1974; Fuller, 1984; Rothengatter, 1988, 2002). The potential impact of behaviour based PAYD is important, as the earlier provided estimates for the effectiveness of PAYD insurance are mostly based on a simple mileage based charge (Harvey and Deakin, 1998; Adkins, 2004; Balcombe et al., 2004; Litman, 2005, 2011; Bordoff and Noel, 2008) due to the well-established link between mileage and accident risk (Bordoff and Noel, 2008; Litman, 2011). Therefore, if more behavioural focused PAYD insurance was effective, in addition to a mileage based system, the positive impacts on society may be further enhanced.

When examining the possibilities of behaviour based PAYD insurance there is one promising behavioural candidate that could be used with modern technology; acceleration behaviour. Acceleration behaviour can be taken as an indication of both risky and environmentally unfriendly driving and is relatively easily monitored by modern telematics (AfWählberg, 2008; Barkenbus, 2010; Dorn, 2014). In addition to acceleration, given that telematics PAYD already tends to involve GPS tracking, there is also an opportunity to add advisory intelligent speed adaptation (ISA) to telematics based PAYD insurance. Simply put, advisory ISA provides warnings to drivers when they exceed the speed limit and has been shown to enhance the impacts of PAYD insurance (Lahrmann et al., 2012), as well as having significant speed reducing qualities by itself (e.g., Brookhuis and de Waard, 1999; Sundberg, 1999; Päätaalo et al., 2002; Lahrmann et al., 2012).

When considering PAYD insurance, behaviour based or otherwise, one way to look at PAYD is effectively a delivery system for incentives, i.e. for rewards and penalties. Therefore, it is important that the incentives are structured and presented correctly within any PAYD insurance product to maximise their effectiveness. Both rewards and penalties are effective when behaviour is relatively certain to be rewarded or penalised and when the reward or penalty follows swiftly after the target behaviour (Skinner, 1974; Abrahamse et al., 2005; Lehman et al., 2014). However, when it comes to rewards vs. penalties the advice from psychology is clear. Rewards are preferred and penalties, while they can still be effective under some circumstances, should generally be avoided or used sparingly (Thorndike, 1911; Watson, 1917; Skinner, 1953, 1974; Renner, 1964; Cameron and Pierce, 1994; Lattal, 2010; Gneezy et al., 2011). Rewards are favoured as they communicate information on what should be done in the future, rather than just saying that someone has done something wrong. Rewards also have the potential to create positive associations between receiving the reward and otherwise somewhat dull tasks, such

as driving safely (Bandura, 1986). Importantly for PAYD, where savings on a moment to moment or even month to month basis are expected to be somewhat small, the size of a reward has also been shown to be less important than the speed and certainty with which the reward is received (Skinner, 1974; Bjørnskau and Elvik, 1992; Zaal, 1994). Indeed, in terms of reward size, there is evidence to suggest that instead of directly giving feedback on monetary savings, credit points or some other medium could be used. It turns out that individuals are not particularly sensitive to the trade-offs between this medium and the eventual reward (Hsee et al., 2003; Bagchi and Li, 2011). This means that points could be varied more freely or in larger amounts but trade off to relatively small financial savings while still having a significant impact on driver behaviour.

That is not to say that rewards have not been criticised and there is indeed considerable debate about the potentially negative impacts of providing external rewards on individual's intrinsic motivation to perform behaviours (Cameron and Pierce, 1994; Deci et al., 1999, 2001; Cameron et al., 2001). The debate about the negative effects of rewards is focused on the controlling aspects of giving rewards and has primarily only been examined in tasks that are interesting and in themselves intrinsically motivating (Deci, 1971; Deci et al., 1999, 2001; Kohn, 1999). Therefore, while the possible demotivating effects of rewards are important to be aware of, they may not apply strongly to PAYD insurance that essentially aims to reward relatively dull safety related behaviours. Furthermore, many of the reported negative effects only hold once a reward is removed (Cameron and Pierce, 1994; Cameron et al., 2001). PAYD insurance, however, is a repeated reward that would essentially always be present unless a customer changed to a non-PAYD insurance plan. Still, care should be taken to further minimise any potential negative impacts of providing external rewards and positive feedback by making sure that rewards are provided in a non-judgemental and non-controlling fashion (Brehm, 1966; Skinner, 1972; Deci et al., 1999, 2001).

In terms of the feedback provided by PAYD telematics systems, behaviour based or otherwise, a popular option used by many PAYD systems is to provide feedback via a dedicated website (e.g., Progressive's Snapshot (<http://www.progressive.com/auto/snapshot/>), Esurance's DriveSense (<http://www.esurance.com/discounts/drivesense-discount>), Coverbox (<https://www.coverbox.co.uk/>)). Under these web based systems data on the customers' driving is collected and can be viewed at the customer's discretion via an online web portal. The use of web based feedback is convenient in that it allows for rich data to be presented to customers in a flexible, and perhaps even customer tailored, fashion. However, web based feedback suffers from two major problems. The first is that web based feedback is delayed, in that it is not available until the driver takes the time to check the website. This means that feedback on driving style and current insurance charges is removed from the driving task itself and comes sometime after the behaviour that is intended to be rewarded or penalised has occurred. The second is that customers may very rarely, or even never, take the time to check in on web based feedback. For example in the study of Bolderdijk et al. (2011) it was reported that, despite the effectiveness of the Pay-As-You-Speed system that was examined, the majority of their participants never logged into the provided feedback website. This is particularly significant as in the Bolderdijk et al. (2011) study the participants could earn up to €50 based on their driving, a sum far larger than most PAYD products would realistically offer in the same timeframe, yet even with this large amount of reward on offer participants did not seem motivated to access relatively readily available feedback on their progress towards this reward.

An alternative to web based feedback is in-car feedback where feedback on the driver's behaviour and on the rewards and penalties they have received could be delivered to them in real

time as they drive. Such devices have been used in ISA studies (see e.g., Brookhuis and de Waard, 1999; Vlassenroot et al., 2010), intelligent transport system studies (e.g., Dijksterhuis et al., 2012) and in one Pay-As-You-Speed trial (Lahrmann et al., 2012). In-car feedback devices can provide clear and immediate feedback on a driver's behaviour and monetary consequences; however, they also come with a potential risk of driver distraction (e.g., Jamson and Merat, 2005; Horberry et al., 2006) and a risk of over-reliance on the system (e.g., Parasuraman and Manzey, 2010) that does not exist with a web based system.

It is also assumed that an attractive PAYD product, would benefit and attract customers that usually cannot afford insurance and cautious drivers with 'high risk' aggregate profiles (i.e. some young drivers). In addition, PAYD may be attractive to car owners who allow their children or older parents to drive their cars and want the extra sense of security that comes with the monitoring of driver behaviour (Bordoff and Noel, 2008; Desyllas and Sako, 2013). That PAYD insurance may be attractive to the parents of young drivers, and to some young drivers themselves, is important as young drivers have a high accident risk profile (Groeger, 2006; OECD-ECMT, 2006; Lewis-Evans, 2010; Lahrmann et al., 2012). Also, if behaviour based PAYD insurance could help inexperienced drivers learn to drive safely, it may help form durable habits that last a lifetime. Therefore, this study will also focus on the impact of PAYD on the, high risk, young driver population.

The aim of the study presented in this paper was to investigate the behavioural impact and user experiences of a behaviour based PAYD system, in combination with a simple ISA, within the context of a driving simulator. In addition to examining the potential impact of behaviour based PAYD system this study also examines the impact if the system is tied to either delayed, web based feedback, or to immediate in-car feedback delivered as the participants drove. It was expected that behaviour based PAYD and the ISA would have a positive result in general in terms of reducing rapid acceleration, braking, and speeding, and that the addition of in-car feedback would have a larger and more immediate impact.

2. Method

2.1. Participants

In total 60 participants who were recruited via advertisements around the University of Groningen and on social media completed the experiment. In order to recruit young, yet not totally inexperienced drivers, the participants had to be 18–25 years old and had to have held their driver's licence for at least one year but no longer than 5 years. Participants were randomly assigned to three groups of 20 participants each, and drove in the simulator six times (practice 1, baseline, PAYD 1/control 1, practice 2, PAYD 2/control 2, and return to baseline) over two sessions, which were one week apart. The control group, whose driving behaviour was not linked to a PAYD reward system, were given €21 for simply driving in the simulator. The web-feedback group received feedback on their driving via a website, which all of them viewed at least once in between sessions. Lastly, participants in the in-car feedback condition received feedback on their driving via an in-car device. The participants in the feedback conditions also received €21 for participating, however, they were told that they would receive €15 plus €6 depending on how they drove (with €3 being available for each PAYD drive). Despite being told that they could earn the extra €6, all participants received the full €21. Ethics approval to conduct the experiment was granted by the University of Groningen psychology ethics committee.

The control group was made up of 7 males and 13 females who were on average 22 years old, and had held their licence for 3 years

on average. The web feedback group was made up of 6 males and 12 females who were on average 21 years old, had held their licence for 2 years on average. The in-car feedback group was made up of 5 males and 15 females who were on average 23 years old, had held their licence for 2 years on average. For all groups, the mean reported monthly mileage was between 100 and 300 km, while most participants reported to drive less than 100 km per month. The reported total mileage for the in-car and control group (12.8K km and 11.3K km on average, respectively) was higher compared to the web group (3.8K km on average). This difference is mainly explained by the absence of a subgroup of more experienced drivers in the web group. For both the in-car and web group, four participants reported to have driven more than 10,000 km in total, with a maximum of 120,000 km and 100,000 km, respectively. In the web group, none of the participants reported to have driven more than 10,000 km. It was decided not to remove this subgroup of more experienced young drivers from the data pool, after comparing the outcome variables and statistical results of a reduced number of participants to entire participant group. As it turned out, data patterns were highly similar and significant test results were identical for all variables, indicating that the more experienced subgroup did not have a deviating impact on overall conclusions.

2.2. Material

2.2.1. The driving simulator

The experiment was carried out using the University of Groningen ST Software® driving simulator, which consists of a fixed-base car mock-up. The simulator has three front facing screens, allowing participants a 180° view, and one extra screen mounted to the back, left of the participant adding an additional 60° of view necessary for merging into motorway traffic. Data of the participant's driving behaviour were collected at a rate of 10 Hz.

The simulated road was 28.2 km long and involved driving through a mixture of urban (two villages), rural, and highway situations within a Dutch context, and took a little over 26 min to drive on average. The drive featured other vehicles, controlled by the simulator software. In most cases this involved a constant medium density stream of oncoming traffic. However, during the car following scenario (see below) there was a constant high density stream of on-coming traffic in order to prevent overtaking. Furthermore, for most of the drives there was at least one vehicle following the participant's vehicle, in order to create some feeling of pressure, and during the highway section of the drive traffic was also present in front of the participant. During each drive, route instructions were given to the participants verbally (for example "Turn Left") and via a small onscreen navigation HUD.

The simulated road involved several situations that were aimed to investigate the behaviour of the drivers when under the secondary load of driving in the PAYD conditions. These included four scenarios where the participants had to give way to a car that had right of way and approached from a side street to the right of the participant, four scenarios where cars approached from a side street on the left and gave way to the participants, two gap acceptance scenarios, and one car following scenario. In the gap acceptance scenarios, participants had to drive through or turn across a stream of oncoming traffic or cross a stream of traffic intersecting from right to left. The traffic started with a gap between cars of 1 s that increased by 1 s with every gap. The accepted gap time and distance to the approaching cars was then recorded by the simulator. In the car following scenario the participants were stopped at a traffic light and a car manoeuvred in front of them. The participants were then asked to follow that lead car and were instructed to try to maintain a constant 2 s following

distance. The lead car was programmed to vary its speed between 60 and 80 km/h (the speed limit at the location being 80 km/h) and to accelerate and decelerate within a random frequency pattern between 0.025 and 0.05 Hz (i.e. 20 and 40 s). At the other intersections the participants had to either give way to a car or realise they had right of way and that the other car was giving way to them. The exception was during the second PAYD drive (see Section 2.3 below for more details) where a car that would usually give way in the second village instead would cut off the participant, the idea being that the participants may have got used to the cars giving way to them. This was implemented to see how they would react while also receiving feedback in the relevant conditions.

2.2.2. The reward and feedback system

The PAYD system was created exclusively for the experiment and ran in a Node.js Server-Side JavaScript environment on the simulator computer. It sampled speeding behaviour in addition to both lateral and longitudinal acceleration and deceleration behaviour at a rate of 10 Hz. During the PAYD drives, the system applied penalties or gave a reward based on the observed behaviour. Participants were rewarded €0.0015/s if they drove smoothly and did not break the speed limit. Conversely if they accelerated, braked, or cornered too rapidly or harshly, or broke the speed limit they lost €0.03/s, with at least 0.5 s of the behaviour being needed to trigger the penalty. The €0.0015/s rate was chosen as a rate that meant that even a carefully driving participant would not quite make €3 during a normal drive, meaning that nobody would easily earn the maximum reward of €3. Furthermore, when a participant's vehicle was completely stopped, for example when waiting at a crossing, no money could be earned or lost. Harsh braking or cornering was defined as a deceleration or lateral acceleration greater than 3 m/s^2 . Due to differences in acceleration generated as a vehicle switches between gears, rapid acceleration was defined at a baseline as more than 3 m/s^2 , however, this threshold was modified by a factor of 0.0112 at speeds below 60 km/h and at an additional factor of 0.0112 at speeds above 60 km/h. This modification, by a factor of 0.0112, was based on the work on a similar system used in trucks by Ullberg (2009). An acceleration and deceleration limit of 3.0 m/s^2 was taken from the 2.5 m/s^2 limit used by Ullberg (2009) and then adjusting it so it felt appropriate for the driving simulator. While this does mean that the 3 m/s^2 limit is somewhat subjective and specific to the driving simulator software used, it is also a somewhat conservative limit with other research suggesting that around 1.5 m/s^2 acceleration or deceleration is normal (Bonsall et al., 2005). Speeding was defined

as travelling more than 5 km/h over the current speed limit, which is within the definition of 8 km/h as used by the Dutch police for a speeding limit above 100 km/h (Dutch Public Prosecution Service, www.om.nl).

2.2.2.1. The web feedback system. The feedback in the web condition was housed on a webserver, the address of which was emailed to the participants at the end of the first experimental session. The website was not interactive and simply displayed information on their driving behaviour. That is, it showed the participants how often they had violated the behavioural thresholds and how these violations had reflected their potential reward (see Fig. 1A). Each website was individually generated and tracking was embedded. Participants in the web condition were told that they must visit the site and at the start of the second session the experimenter checked if the website had been visited at least once, which was the case for all participants.

2.2.2.2. The in-car feedback system. The in-car feedback system consisted of a driving user interface (UI) (Fig. 1B,C) and an end of drive UI that was identical to the web feedback information (Fig. 1A). The design of the in-car driving UI was based on an online survey of potential UI alternatives, which was completed by 119 individuals (70 male, 48 female, 1 other). The driving UI (Fig. 1B,C) was constantly updated and provided several types of feedback. Firstly, the top pane showed the momentary total amount of earned money and a green or red arrow pointing up or down indicating if money was currently being earned or lost. Secondly, the middle pane provided real-time feedback on cornering (lateral acceleration in either direction), braking, and acceleration behaviour. In addition, the vertical dashed line in each bar indicated the threshold value for the penalty on the driving parameters and the bar changed colour from green to red when this value was exceeded. Thirdly, in the bottom pane, the current speed limit was shown which flashed red in case the speed limit was broken: an intelligent speed adviser. Furthermore, if any of the penalised behaviours continued for more than 6 s a warning tone would sound that would then repeat itself every 6 s until the behaviour returned to normal, rewarded, levels. As part of the previously mentioned survey the UI was also evaluated in order to ensure that colour-blind individuals could distinguish the above state changes, in that the red and green colours were distinct enough from each other in brightness and contrast. Fig. 1B shows the UI in a state where the participant is gaining money and Fig. 1C shows an example of the interface when in fact two thresholds

Fig. 1. An illustration of feedback as given via the web and the in-car system (A) and via the in-car system only (B and C). (A–C) All text is translated to English for the readers' convenience, however they were presented in Dutch to the participants. (A) Provides an overview of the monetary results and the associated driving behaviour events. (B) The interface in reward mode. (C) The interface in penalty mode.

were passed at the same time (speeding and harsh acceleration). This resulted in the normal rate of decrease of the total amount of earned money (€0.03/s).

The in-car UI itself was running on a HTML5 web platform communicating with the control software over web-sockets. The UI was presented to the participants on a 5th generation iPod touch via a “Kiosk Pro Lite” application, and is shown mounted to the simulator in Fig. 2. The iPod touch was, via markings on the simulator frame, always mounted in the same place, and was only present during the relevant feedback drives for those who were in the in-car feedback condition.

2.2.3. Questionnaire

The questionnaire in the experiment was (in Dutch) carried out online via an ASUS Transformer Pad TF300T tablet running the Android operating system, version 4.1.1. The questionnaire contained instructions about the experiment and basic demographic questions about the participant's age and driving experience. The questionnaire also introduced the idea of PAYD to all groups and asked participants if they would be interested in such a product. This question about PAYD was asked once when collecting demographic data, before the participants had driven in the experiment, and once again at the end of the experiment.

After each drive (excluding the practice drives) the participants were also asked to rate (from 1 to 7) difficulty, risk, and distraction based on the following scales; in general, how difficult was this drive? Where one was “Not difficult at all” and seven was “Extremely difficult”; in general, to what extent did you feel that you were at risk during this drive? Where one was “No risk” and “Extreme risk”; in general, to what extent did you feel distracted

during this drive? Where one was “Not distracted” and seven was “Extremely distracted”.

In the cases in which participants drove with an in-car device (two drives over two sessions – see Section 2.3 below) participants were asked to also provide the following ratings on a 1–7 scale where one was equal to “not at all” and seven was equal to “extremely”; (1) how clear the information provided on the interface in the vehicle was related to the gain and loss of money, (2) how easy the interface in the vehicle was to use, (3) how accurate the information provided on the interface in the vehicle was, and (4) how distracting the interface in the vehicle was. Participants in the in-car condition were also asked if they would like to receive information about their driving habits when driving via a similar UI in the real world. This question about whether they wanted the device in reality was asked for the in-car feedback participants twice, first after the first PAYD drive (at the end of session 1) and then again at the end of the experiment after the return to baseline drive (at the end of session 2).

The web feedback participants were also asked to evaluate the web feedback with the same questions that were presented to those in the in-car feedback condition. However, the web feedback participants only received these questions once, at the start of the second session, after they had viewed the web feedback. They were also asked if they would like to have feedback on their driving presented in the same fashion as it was in the experiment, but again only once, at the end of the experiment after the return to baseline drive (session 2). Participants were also asked about their website viewing behaviour. The number of times that the website was viewed ranged from one to four times ($M = 2.0$ times, $SD = 1.0$), and eight participants viewed the website once. In addition, the last visit to the website prior to the second session, ranged from the same day (zero days ago), to directly after the first session (seven days ago; $M = 3.3$ days ago, $SD = 2.3$).

2.3. Procedure and instructions

Participants came to a total of two sessions. In the first session the participants were required to fill in a survey that collected some basic demographic data. The participants then drove in the simulator three times in each session and were told before each ride to drive as they would in their own vehicle. After each drive, participants were presented with a questionnaire and asked to provide the ratings described in Section 2.2.3. The first drive in each session was a 10–12 min practice drive, without the PAYD system and involved the participants driving the test road up until the end of the car following task. At this point, three participants felt simulation sick and did not continue with the experiment, leaving 60 participants in the data pool. During the first session, participants completed a baseline drive before the PAYD drive. During the second session, this order was reversed.

In order to apply some time pressure all participants were asked to complete each experimental drive within 30 min, a relatively easily achievable task, also if the speed limits were respected. This was done as one way to ‘game’ the system would be to drive very slowly (since money accrued every second as long as the participants were moving).

As part of the initial instructions, participants who were in the PAYD groups were already informed in detail of the PAYD reward system before the first practice drive and were reminded of the PAYD system before each PAYD drive. In addition, before the baseline drives, these participants were told that no feedback would be given on their driving behaviour and that they could not earn any money based on the way that they drove. Once the participants had finished all the drives they were thanked for their participation, debriefed on the experiment, including the deception, and given the full €21.

Fig. 2. The iPod mounted on the simulator frame.

2.4. Analysis

To begin with, subjective ratings (usability ratings for the interfaces and drive ratings) and the driving behaviours that determined the feedback leading up to monetary losses (accelerating, braking, steering, and driving speed) were analysed to provide a general comparison between the groups and the drives. To compare the net monetary earnings between the various conditions and the contributions of the four driving behaviours on these earnings, the average value per minute was used rather than the total monetary value (similar to Musicant et al., 2014). This was done to account for the potential that participants in the feedback conditions took more time to drive and therefore, earned more money just based on time driven rather than their behaviour. Secondly, since participants encountered several traffic scenarios within each drive (giving way to cars from the left and right, gap acceptance, car following, and a highway), analyses were also performed for these specific situations.

In Section 3, subjective data, net monetary values, and monetary losses split up for each driving behaviour are presented. However, a full description of all driving behaviours, both averaged for each drive and in specific driving situations requires a lengthy report (Dijksterhuis et al., 2014) and therefore, a selection was made that still reflects the total investigation, but at the same time shows the reader the most relevant results. That is, the driving behaviour results provided in the current paper are limited to the largest contributor to the monetary losses (speeding) and to two indications of risky driving behaviour. Firstly, the gap time between two subsequent cars between which the participant navigated two intersections. Secondly, minimum time headway during the car following task. A minimum time headway is determined at the moment that a participant stops approaching the lead car and start increasing time headway again; this is an oscillating pattern. Time headway is defined as the time it takes for the following car to get to the lead car's current position.

In summary, there were three groups of participants and each participant completed six drives (three per session), but only the baseline, PAYD 1, PAYD 2, and return to baseline conditions were analysed as data were not collected during the practice drive. However, only the participants in the in-car and web group were able to receive an extra reward during the PAYD drives. In total, this resulted in a mixed statistical design for most analysed variables, consisting of two within-subject factors: Session (the first vs. the last) and PAYD (baseline vs. PAYD/control drives), and one between-subjects factor: Group (control, in-car feedback, and web feedback). However, another within subject factor (Intersection) was added to test accepted gap time since there were two gap acceptance situations in each drive (see Section 2.2.1 for more details). Note that the control group was never exposed to the PAYD system. However, the drives during which the participants of the control group would have received feedback if they would have

been selected for one of the other two groups, were included in the analysis. To test the differences between the various factors, repeated measures analysis of variance was performed using IBM SPSS Statistics 20. Bonferonni corrected post hoc tests were used when appropriate. Considering the experimental setup, potential main effects are likely to be best explained in terms of interactions, especially the PAYD factor which includes a control level. Therefore, the main focus in Section 3 will be on reporting these interactions. Finally, since the interface usability ratings were only requested from the in-car group after the feedback drives, paired sample *t*-tests were performed to check for differences between the first and second drive on each usability variable. Alpha was set to 5% for all tests.

3. Results

3.1. Subjective ratings

To start with, Fig. 3A shows mean usability ratings. As can be seen, for both drives during which in-car feedback was provided, all interface ratings were around the middle of the rating scale, ranging between 3.9 for distraction during the first feedback drive and 5.4 for clarity and ease of use during the second feedback drive. As might be suspected from the small differences between the first and second PAYD drive on each usability variable in Fig. 3A, none of these returned a statistical significant difference.

Directly before the first drive in the first experimental session and directly after completing the second session, participants were asked whether or not they would be interested in PAYD-based insurance. As can be seen in Fig. 3B, about half of all answers were positive, ranging from 45% for the in-car group when they were asked for the second time, to 60% for both the web and control group when asked this question before the first and after the second drive, respectively.

As can be seen in Fig. 4, ratings of experienced difficulty, risk, and distraction as given after each drive are relatively low on average, ranging between 2.0 and 3.5 across all three variables. Group differences were not revealed for any of the variables, even if it seems that the web group consistently rated driving as slightly more difficult (Fig. 4A and Table 1). However, difficulty ratings were lowest after second baseline drive (2.1 vs. 2.6 points across the other three drives on a scale from 1 to 7), which explains the main effect of PAYD and the interaction between PAYD and Session (see Table 1). Next, experienced risk after the first PAYD drive was rated lower than any of the other drives, while the second PAYD drive was rated highest (see Fig. 4B and Table 1). More specifically, the mean risk ratings for Baseline 1, PAYD 1, PAYD 2, and Baseline 2, were 2.6, 2.2, 3.3, and 2.5, respectively. Finally, differences in distraction ratings were not found for any of the experimental factors.

Fig. 3. Mean usability ratings for the in-car interface and general interest in a PAYD-based insurance fee (B). (A) To be clear, these ratings could only be obtained from the in-car group ($n = 20$) during the PAYD drives. Error bars represent the standard error.

Fig. 4. Mean ratings of experienced difficulty (A), risk (B), distraction (C) for each of the drives. Error bars represent the standard error.

3.2. Rewards and driving behaviour

The most striking overall result, in terms of the monetary reward system, is that both the in-car and the web group outperformed the control group substantially during all four drives (see Fig. 5A and Table 2). In addition, monetary performance were higher during PAYD drives and higher during the first experimental session. However, these main effects are largely dependent on the more interesting interactions between them.

To begin with, when the in-car and web group could not receive an actual reward (i.e. in the baseline and return to baseline drives), their performance would have resulted in a loss ($M = -0.06$ €/min across these two groups), whereas they were earning money during the PAYD drives ($M = 0.06$ €/min across these two groups;

see Fig. 5A). The control group on the other hand, did not show a similar change. At this point it should be noted that the web group was already earning money before feedback was provided. In addition, the feedback groups were already losing 0.07 €/min less than the control group during the first baseline drive, and were doing 0.15 €/min better the during second baseline drive. Together, these patterns contributed to the interaction between PAYD and Group as reported in Table 2. In addition, the difference between the feedback groups and the control groups was at its maximum (0.26 €/min on average) during the second PAYD ride, i.e. after the web group had also received feedback, when the performance superiority of the in-car group over the web group of 0.04 €/min during the first session, was reduced to 0.01 €/min. Another interesting observation is the reduced size of the error bars when the feedback groups had actually received feedback.

Another striking result is the large average performance decrease between the first and second baseline drive ($M = -0.06$ vs. $M = -0.14$ €/min), which was not the emerging overall pattern during the PAYD drives, contributing to an interaction between Session and PAYD (see Table 2). Thirdly, an interaction between Group and Session was not present (or only marginally present), however, when looking at Fig. 5A two trends may be distinguished. The first trend is a steady performance decline (see Fig. 5A) of the control group from the first to the fourth drive (from $M = -0.12$ to $M = -0.24$ €/min). In addition, the other groups showed a decline in baseline to return to baseline performance from the first to the second session ($M = -0.03$ and $M = -0.09$ €/min across the in-car and web group).

Fig. 5B shows the mean average monetary loss per minute during each of the drives. Unsurprisingly, the overall monetary loss pattern is consistent with Fig. 5A and will therefore not be further elaborated upon. In addition, Fig. 5B shows the contribution of each parameter to these losses for risky driving, i.e., harsh cornering, harsh braking, harsh acceleration, and speeding. As can be seen, speeding was a prominent contributor to monetary losses when participants were either unaware of the PAYD system or knew that it was not linked to monetary rewards (the control group and during baseline drives). However, during the feedback rides, both the absolute and relative contribution of speeding dropped substantially. For example, the losses due to speeding during the first baseline ride were 0.05 €/min for both the in-car and web group (accounting for 41% and 42%, respectively for the total losses), but this was reduced to less than 0.00 €/min for the in-car group and 0.01 €/min for the web group (which is 16% and 22% of the total losses for that drive). A similar, and even more distinct pattern emerges from the second PAYD ride to the second baseline ride for these two feedback groups. Although not presented separately, it is also interesting to note that the number of speeding events decreased by 90% and 94% for the web and in-car group, respectively during the PAYD drives, as compared to the baseline drives.

Table 1

Multivariate test results for experienced difficulty, risk, and distraction (Fig. 4). Note that the control group was never exposed to the PAYD system. η_p^2 (partial eta-squared) represents the effect size. df is degrees of freedom. Significant effects ($p < 0.05$) are shown in bold.

Effect	Subjective ratings									
	df1,2	Difficulty			Risk			Distraction		
		F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Group (G)	2,57	0.762	0.471	0.026	0.132	0.877	0.005	0.213	0.809	0.007
PAYD/Control (P)	1,57	6.090	0.017	0.097	2.540	0.117	0.043	1.069	0.306	0.018
Session (S)	1,57	0.049	0.099	0.047	13.242	0.001	0.189	1.461	0.232	0.025
P × S	1,57	0.162	0.004	0.140	31.818	<0.001	0.358	<0.001	1.000	<0.001
S × G	2,57	0.001	0.966	0.001	0.431	0.652	0.015	1.971	0.149	0.065
P × G	2,57	0.011	0.723	0.011	0.121	0.886	0.004	1.257	0.292	0.042
P × S × G	2,57	0.008	0.790	0.008	1.504	0.231	0.050	2.688	0.077	0.086

Fig. 5. Average net monetary earnings (A) and losses (B) per minute, and mean driving speed (C) for each of the drives. (A) Gains minus losses. (B) Losses only, split up for each of the four criteria. (C) Mean driving speed for the first encountered village and for the total drive. Note that the control group was never exposed to the PAYD system. Error bars represent the standard error.

As speeding behaviour decreased, the relative contributions to monetary losses due to accelerating, braking and cornering behaviour increased, even if the absolute losses due to these

parameters also decreased. For example, when just looking at the second PAYD drive, when both feedback groups had received feedback and compared to the first baseline drive, a decrease in

Table 2
Multivariate test results for net monetary earnings per minute: gains minus losses, and driving speed in the first village and for the total drive (Fig. 5). η_p^2 (partial eta-squared) represents the effect size. df is degrees of freedom. Significant effects ($p < 0.05$) are shown in bold.

Effect	Rewards and driving speed									
	df _{1,2}	Net monetary earnings			Speed, first village			Speed, total drive		
		F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Group (G)	2,57	13.595	<0.001	0.323	29.638	<0.001	0.514	10.503	<0.001	0.269
PAYD(Control (P))	1,57	41.159	<0.001	0.419	137.367	<0.001	0.710	88.237	<0.001	0.608
Session (S)	1,57	6.867	0.011	0.108	0.446	0.507	0.008	3.147	0.081	0.052
P × S	1,57	15.847	<0.001	0.218	28.969	<0.001	0.341	51.685	<0.001	0.476
S × G	2,57	2.524	0.089	0.081	5.911	0.005	0.174	1.817	0.172	0.060
P × G	2,57	9.969	<0.001	0.259	51.744	<0.001	0.649	28.440	<0.001	0.499
P × S × G	2,57	0.138	0.871	0.005	0.444	0.644	0.016	0.475	0.624	0.016

losses of 0.03 €/min (71%) due to harsh accelerations, 0.01 €/min (58%) due to harsh braking, and 0.01 €/min (76%) due to harsh cornering was observed for the web group while this number was decreased with 0.04 €/min (90%) for harsh accelerations, 0.01 €/min (76%) for harsh braking, and 0.01 €/min (86%) for harsh cornering in the in-car group. Finally, it is worth noting that the monetary advantage of the in-car group over the web group during the first feedback drive (see Fig. 5A) was mostly caused by harsh accelerations by the web group (see Fig. 5B).

The averaged data of the largest contributor to monetary losses, driving speed, is shown in Fig. 5C (and reported in Table 2), split up for the first encountered village and the total length of the drive. Focussing on the total drive, several driving speed effects were revealed, which reflect to a large extend the patterns found in Fig. 5A. Again, the interaction effects are most relevant in describing these results. To start with, driving speed differences between the groups are most pronounced during the PAYD drives, when the control group drove 71.5 km/h on average, while the in-car and web groups driving speed was 63.5 km/h and 65.6 km/h. In addition, the speed reduction between the baseline drives and the PAYD drives was 6.1 km/h on average for the in car group and 3.6 km/h for the web group, while the control group's driving speed remained relatively unaltered with an increase of 0.1 km/h. These pattern demonstrate the main effects of PAYD, Group, and the interaction between these as shown in Table 2.

Driving speeds in the first encountered village were lower compared to the drive in total, which also included roadway sections with speed limits of 80, 100 and 130 km/h. However, the driving speed patterns are highly comparable, except that control group showed a relative large speed increase from the first to the second session (of 1.2 km/h) compared to a smaller decrease for the in-car and web group (0.1 and 0.6 km/h, respectively), which contributed to the interaction effect between Session and Group as reported in Table 2.

As described in Section 2.2.1, each participant encountered several driving situations during each drive and a selection of these is reported here. As can be observed from Fig. 6A, the gap time between two subsequent cars that the participants accepted was largest for the in-car group for most situations while the control group's accepted gap time was smallest on average, resulting in a small effect of Group. Also, post hoc tests showed that the web group ($M=6.18$, $SD=1.22$ s) did not differ significantly from the other groups, while the in-car group ($M=6.36$, $SD=1.23$ s) and the control group ($M=5.82$, $SD=1.05$ s) did differ. The specific intersection and the session number affected accepted gap time to

a somewhat larger degree, as the average accepted gap time was lower for the second intersections ($M=5.7$ vs. $M=6.6$ s) and lower during the second session ($M=5.9$ vs. $M=6.3$ s). Moreover, this decrease from the first to the second session was more pronounced for intersection 1 (a 0.64 s decrease) compared to intersection 2 (a 0.19 s decrease), resulting in an interaction between these two factors (see Table 3).

As is apparent from Fig. 6B, the mean minimum time headway (THW) during the car-following task was affected by the presence of the reward system. Compared to the baseline drives, THW during the PAYD drives was higher (a main effect of PAYD; $M=2.4$ s vs. $M=3.2$ s on average). However, this change in THW was more pronounced for the feedback groups (an increase of 1.6 s, 0.8 s, and -0.1 s for the in-car, web, and control group, respectively), resulting in the interaction between Group and PAYD as reported in Table 3. This difference between the groups during the PAYD drives also lead to a main effect of Group, and especially the overall difference between the in-car and the control group ($M=2.83$ s, $SD=1.15$ s and $M=3.38$ s, $SD=1.53$ s, respectively), which tested significantly in post hoc analyses. A second interaction was found between PAYD and Session. That is, the overall increase in THW between driving with and without the PAYD system for the first session was 0.5 s while for the second session, this difference was larger during the PAYD drive (1.1 s).

Table 3

Multivariate test results for accepted gap time and mean minimum time headway (Fig. 6). η_p^2 (partial eta-squared) represents the effect size. df is degrees of freedom. Significant effects ($p < 0.05$) are shown in bold.

Effect	df1,2	Gap time			Mean minimum time headway		
		F	p	η^2	F	p	η^2
Group (G)	2,57	3.565	0.035	0.111	7.450	0.001	0.207
PAYD/Control (P)	1,57	0.445	0.508	0.008	67.797	<0.000	0.543
Session (S)	1,57	27.705	<0.000	0.327	1.166	0.285	0.020
Intersection (I)	1,57	71.497	<0.000	0.556	–	–	–
G $\times$ P	2,57	1.843	0.168	0.061	26.627	<0.000	0.483
G $\times$ S	2,57	0.368	0.693	0.013	0.209	0.812	0.007
G $\times$ I	2,57	2.165	0.124	0.071	–	–	–
P $\times$ S	1,57	0.680	0.413	0.012	14.884	<0.000	0.207
P $\times$ I	1,57	0.263	0.610	0.005	–	–	–
S $\times$ I	1,57	10.012	0.002	0.149	–	–	–
G $\times$ P $\times$ S	2,57	0.337	0.715	0.012	0.309	0.736	0.011
G $\times$ P $\times$ I	2,57	0.192	0.826	0.007	–	–	–
G $\times$ S $\times$ I	2,57	0.072	0.931	0.003	–	–	–
P $\times$ S $\times$ I	1,57	0.909	0.344	0.016	–	–	–
G $\times$ P $\times$ S $\times$ I	2,57	0.177	0.838	0.006	–	–	–

Fig. 6. Gap acceptance (A) and car following (B) driving risk parameters. (A) Mean gap time between two subsequent cars between which the participant navigated two intersections. (B) Mean minimum time headway during the car following scenario. Note that the control group was never exposed to the PAYD system. Error bars represent the standard error.

4. Discussion

Pay-As-You-Drive (PAYD) is a way to directly connect the individual driver's behaviour to the insurance premium, which potentially makes vehicle insurance more actuarially accurate. Most existing usage based insurance products, and their associated predicted or reported benefits, are mileage based systems where the driver is charged based on how far they drive (Harvey and Deakin, 1998; Adkins, 2004; Balcombe et al., 2004; Bordoff and Noel, 2008; Litman, 2005, 2011; Lahrman et al., 2012). The body of work presented in the current paper was aimed at investigating the potential impact of including a more elaborate set of risk-related behaviours in a PAYD system, namely accelerating, braking, speeding, and steering behaviour. In addition, existing PAYD insurance systems usually deliver feedback of individual driving behaviour through a web-based interface that is viewed after the actual drive. Since psychological literature suggest that rewards and penalties are more effective if administered swiftly after the target behaviour (Skinner, 1974; Abrahamse et al., 2005; Lehman et al., 2014), the effectiveness of immediate feedback through an in-car interface was compared to delayed feedback through a web based interface.

A number of important results came out of these studies. To start with, compared to the baseline drives, driving behaviour was improved during the PAYD drives for both feedback groups as participants reduced the number of events, and subsequently, time spent on harsh cornering, acceleration, braking and speeding behaviour which lead to improved monetary performance. These reductions were over 50% for all behaviours, going up to a 94% decrease in the number of speeding events for the in-car group, which turned out to be the main contributor to the differences in monetary rewards followed by acceleration behaviour. Also, the feedback groups outperformed the control group across all four drives, especially during the PAYD drives when monetary rewards were coupled to driving behaviour, showing that PAYD impacted driving behaviour both within and between groups. These results provide a signal for the potential of a behaviour based PAYD system to elicit smooth driving behaviour, at least in the short term, which could add to the advantages of a purely mileage based PAYD insurance or a mileage based insurance complemented by speeding behaviours as reported in literature (Buxbaum, 2006; Mazurek and van Hattem, 2006; Bolderdijk et al., 2011; Greaves and Fifer, 2011).

However, the various interactions that were observed between the experimental sessions, groups, and the presence of a PAYD system, have several more implications. To start with, the hypothesised advantage of immediate in-car feedback over delayed web based feedback in terms of monetary performance was clear during the first PAYD drive. However, after both groups had received feedback, this difference was substantially reduced to 0.01 €/min. Even if this difference could be quite meaningful over time if maintained, it must be concluded that the overall advantage of the PAYD groups vs. the control group is the most eminent result of this study. This is apparent in both the monetary improvements and the underlying driving behaviours. However, when generalizing these results, it is of paramount importance to take into account that participants were required to view the website which strongly implies that the certainty that drivers actually view feedback is more relevant than the immediateness of feedback. An important finding as other research (e.g., Bolderdijk et al., 2011) has found that people operating under PAYD system in the real world often do not check web based feedback systems, even when large monetary amounts are at risk. Therefore, it could be argued that in-car feedback should be preferred over web feedback, assuming that in-car feedback is a surer way of delivering information. On the other hand, these considerations also suggest

that finding alternative ways to inform the driver of monetary consequences may be worth investigating. For example, through the use specific software applications, push notifications, or through social media on nomadic devices, either directly before a ride, directly after or from the comforts of home.

Interestingly, driving behaviour in two specific driving situations seemed to be even more significantly improved in the in-car group. To start with, the in-car group behaved more conservative when choosing the moment to cross roads between intersecting traffic. However, given that this difference was already present during the first baseline drive during which the conditions for the in-car and web group were equal, we cannot conclude that in-car feedback caused this behaviour. In contrast, initial differences between the in-car and web group for the mean minimum time headway did not exist, suggesting that the relative large distance kept by the in-car group when following a lead car on rural road conditions, was likely triggered by the immediate feedback as given by the in-car interface even though these car following behaviours were not directly rewarded. In addition, a clear subjective disadvantage of using in-car feedback was not found, as participant perceived the in-car device as clear, easy to use and accurate, but moderately distracting and did not perceive these drives as being more difficult or risky compared to the ratings of the web group. Taken together, it can be concluded that a moderate advantage of using immediate in-car feedback over delayed web-based feedback was observed.

Even though the monetary performance of the web group before they had received any kind of feedback, was low compared to in-car group, it was still substantially higher compared to the control group. This observation suggests that just being aware that a PAYD system is monitoring driving behaviour and determines financial gains already changes driving behaviour to an extent. This was also an unintentional finding of Bolderdijk et al. (2011) who reported on an eight months PAYD field trial, during which participants seldom checked the website more than once, but which succeeded nonetheless in changing driving behaviour. In the current study, even during the first baseline drive, when the feedback groups were explicitly told that their driving behaviour would not be linked to a reward system, there is already a distinct difference between the control group and the feedback groups. At that point in the experimental procedure, all groups had been made aware of the possible existence of a PAYD insurance by asking how they would like such a product, but only the feedback groups were already informed in detail of the monetary consequences of their driving behaviour later on in the experiment. Speculatively, participants may have been practising for the actual PAYD drives, or became more aware of their driving style.

Finally, there is a relapse in monetary performance for the feedback groups going from the second PAYD drive to the second baseline drive, which was always the last drive of the participant. It indicates that for the young group of drivers used for the current study, a large part, but not all, of the effects of PAYD only last while drivers can actually earn rewards (see also De Waard et al., 1999). This is in line with other pay as you drive investigations which observed that the removal of rewards in a young driver group, even after months of driving with a form of PAYD in real traffic, resulted in a return to driving behaviour as measured before the reward system was introduced (Bolderdijk et al., 2011; Lahrman et al., 2012). Even so, it would still be relevant for to further investigate the interactions between the length of exposure to a PAYD system and the length that new behaviours survive once the rewards are removed, given that young drivers are overrepresented in accident statistics (see e.g., Engström et al., 2003; Williams, 2003; Mayhew et al., 2003; OECD-ECMT, 2006; Ouimet et al., 2010).

Interestingly, it appears that the majority of the impact of the behavioural monitoring was on participants speeding behaviour.

One possible explanation for this is that speed is the easiest variable for a driver to control and indeed while drivers in the web feedback condition did not have feedback on speeding, they could still monitor the speedometer and gain feedback in this fashion. This indicates that if behavioural PAYD is going to be implemented then speed monitoring may be a crucial component of the system, a finding that meshes well with past studies of ISA effectiveness (e.g., Brookhuis and de Waard, 1999; Sundberg, 1999; Pääta et al., 2002; Lahrman et al., 2012).

So far, the experimental limitations of forcing every participant in the web-feedback group to actually check the website, and investigating the effects of PAYD across just two rides were already discussed. The latter highlights the need to investigate the sustainability of PAYD effects on driving behaviour both before and after a reward and penalty system is withdrawn. However, another weakness of all experimental trials of PAYD insurance, including the current study, is that unlike with real PAYD insurance customers, experiment participants never had to pay any costs and could only receive rewards based on their driving behaviour. That participants in experiments cannot be charged is a somewhat unavoidable aspect of experimental research due to ethical concerns and highlights the need for evaluations of commercial PAYD insurance products. Another limitation of our study is that no mileage charge was included in our study. A mileage charge was not introduced as we were working on a reward model, where we could not take money from participants. However, since mileage charges alone may be effective, it may be that adding behavioural charges to them may have an additional impact. This should be investigated in on-road studies or implementations of PAYD. A final limitation is that even given the small rates of gain used in this study (0.0015 €/s of good behaviour) this is an unrealistically large amount of money to expect to be being saved per second under a real PAYD system. Given that merely being monitored seems to have quite a significant impact on behaviour, the size of the moment-to-moment reward may not be an issue, but it is again something that needs to be investigated over a longer time period.

5. Conclusions

The presented results show that a broad PAYD insurance, based on multiple risk-related driving behaviours substantially reduces the presence of these behaviours during driving. This indicates that a behaviour based PAYD system could be used to further increase the benefits of a purely mileage based system. The vast majority of the positive effects as compared to a control group applies to both the delayed and immediate feedback systems, although some advantages of immediate feedback and subsequently, the underlying driving behaviours, were also found. However, the results strongly imply that certainty of viewing feedback is a crucial factor for the effectiveness of a PAYD system and not its immediacy. The discussion whether it is better to provide in car feedback or web based feedback should therefore be shifted to how to maximise the certainty of feedback, preferably in real world settings. In conclusion, this paper provides further evidence of the benefits of PAYD insurance and highlights that experimental studies of actual PAYD products should be the next step in investigating the impact of PAYD for both the individual driver and society at large.

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