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The influence of multiple goals on driving behavior: The case of safety, time saving, and fuel saving

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ABSTRACT

Due to the innate complexity of the task drivers have to manage multiple goals while driving and the importance of certain goals may vary over time leading to priority being given to different goals depending on the circumstances. This study aimed to investigate drivers' behavioral regulation while managing multiple goals during driving. To do so participants drove on urban and rural roads in a driving simulator while trying to manage fuel saving and time saving goals, besides the safety goals that are always present during driving. A between-subjects design was used with one group of drivers managing two goals (safety and fuel saving) and another group managing three goals (safety, fuel saving, and time saving) while driving. Participants were provided continuous feedback on the fuel saving goal via a meter on the dashboard. The results indicate that even when a fuel saving or time saving goal is salient, safety goals are still given highest priority when interactions with other road users take place and when interacting with a traffic light. Additionally, performance on the fuel saving goal diminished for the group that had to manage fuel saving and time saving together. The theoretical implications for a goal hierarchy in driving tasks and practical implications for eco-driving are discussed.

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1. Introduction

Driving behavior, like other behaviors, is regulated in accordance with drivers' goals and motives (Summala, 1997) and as with other behaviors, drivers can have multiple goals concurrently. Some of these goals can compete with each other, such as avoiding traffic violations while in a hurry to reach a destination. The aim of the current study is to examine drivers' behavioral regulation when they have to manage multiple competing goals that require different driving styles.

When multiple goals are active, drivers have to prioritize some goals over others and will do so based on the importance of the individual goals and dynamic changes in the environment (Means et al., 1993; Cnossen et al., 2000). This is further complicated by the fact that in dynamic situations the importance of different competing goals can shift very quickly with the changes in the situation. For instance, a driver can be concerned with avoiding delays at one moment but shift to stopping immediately upon recognizing a car pulling out of a parking lot.

The primary way that drivers can prioritize between goals is by regulating the effort they put into different tasks. In this way they

can keep the driving task under control and hopefully still react if safety critical situations arise. For instance, Harms (1991) found that drivers reduced speed and performed an arithmetic calculation task slower when they were driving through villages, where the mental workload is high due to the complexity of the task environment, when compared to driving on a four lane divided highway. In fact, drivers' performance of the arithmetic task degraded and their speed decreased even further when they had to turn left at intersections, which requires even more attention because of the possible interactions with other road users. Similarly, drivers have been shown to increase headway when performing a secondary task in order to keep with safe margins (Noy, 1989, as cited in Cnossen et al., 2000). Hence, drivers seem to have a tendency to drop subsidiary tasks or adapt their safety margins to prioritize safety over other task goals and to stay in control. In this way they hopefully have enough time and space to foresee and react to hazards in the road environment if need be. Indeed, it is assumed that the main task of driving is to maintain control in order to achieve a safe trip (cf. Fuller, 2007).

In particular drivers' regulatory actions to adapt to the dynamics of the current circumstance are a means to keep the driving task under control in order to pursue goal-directed behavior. The driving task itself is, with experience, largely automated, fast, and effortless and remains so unless something critical happens (Bellet et al., 2009) or unless the driver chooses to deliberately monitor vehicle control (Summala, 1997). This means that if there is a deviation from the anticipated situation and therefore the usual

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habitual behavior, drivers tend to take action to avoid negative consequences (Summala, 2007; Saad, 2002), shift between the goals and take further regulatory actions based on the mental representations of the situation in order to maintain control over their vehicle and preferably return to a more typical automated effortless driving style (cf. Brehmer, 1992).

Drivers' performance and the associated behavioral regulation are hypothesized to keep them "within a certain comfort zone", which gives drivers enough time and space for their reactions and is based primarily on the maintenance of learnt and automatic safety margins (Summala, 2005, 2007). It is also assumed that drivers have a satisficing performance criterion for a given goal as long as they are within the comfort zone. Thus, drivers do not try to perform the best action possible for the situation, but rather the action that is good enough. In fact, the limited information processing resources available to drivers in dynamic tasks like driving make it essentially impossible for drivers to completely optimize their goal performance. Also, since drivers have multiple goals that can come into conflict, optimizing performance on one goal may have negative effects for one or all of the other goals. This also means that it is more likely that drivers aim for satisficing performance between their competing goals. The upshot of this is that they are satisfied with a good enough performance that exceeds a certain aspiration level (Summala, 2005, 2007; Sivak, 2002; Boer, 1999; Simon, 1957). What exactly constitutes the aspiration level while driving is still a matter of debate however (e.g. Summala, 2005, 2007; Rothengatter, 2002). In any case the criterion does seem to be related to people's goals and situational factors. Näätänen and Summala (1976 as cited in Summala, 2007) predict higher speed and shorter safety margins when external motives such as time goals, maintenance of speed, or feeling of control are prominent while driving. For instance, a former study showed that time pressure can lead drivers to reduce their safety margins (Van der Hulst et al., 2001). Therefore, drivers can be said to be satisfied with their performance in terms of safety as long as they reach their destination alive, unharmed and without incident, despite the fact that their performance may not be at an objectively optimum level.

With the above in mind, how do drivers balance multiple goals when they are set a strategic goal which requires that they try to optimize their behavior? The current study aims to investigate this question. To do so, in addition to the presumed main goal of driving safely (cf. Fuller, 2007), we added a secondary goal of saving as much fuel as possible during the trip. We chose fuel saving because it would require drivers to consciously monitor their driving behavior and reducing fuel consumption has become an important goal for driving as seen by the implementation of many eco-driving programs during the last decade (CIECA, 2007). Eco-driving aims to reduce the environmental impact of one's driving style, e.g. by maintaining a steady speed, anticipating traffic flow, and accelerating and decelerating smoothly (CIECA, 2007). By doing so an eco-driving style results in less fuel use and a reduction of CO₂ emissions. However the smooth driving style required by eco-driving must also be balanced with managing interactions with other road users and road situations in a safe way.

Participants were also required to drive on both a residential and rural road in the current study. The two different road environments were chosen because of naturalistic differences in task demand they place on the drivers. In particular the results of a study by Harms (1991) suggest that drivers perform better on multiple tasks on rural roads than on urban roads and that drivers' performance is further jeopardized when they have to manage their interactions with other road users at intersections. As such we also presented drivers with several intersection situations in the residential areas.

Another critical condition influencing task demand in driving is available time (Summala, 2007). Drivers have to make decisions

and perform them in continuously evolving situations in real time, which requires drivers to relate the timing of their actions to the dynamic changes of the situation. Time constraints therefore leave limited capacity for information processing (Hancock and Caird, 1993) and increase the task demands of the situation and the difficulty of decision making while driving. With this in mind time pressure was also induced in one of the groups, with the other group serving as a control.

In summary, a fuel saving goal was explicitly set, in addition to a presumed implicit safety goal in order to examine how drivers manage these two goals in different traffic environments, i.e. urban versus rural roads. Also, we specifically created several critical situations that further increased task demands. In addition, we introduced time pressure in half of the sample in order to test how this would influence performance and commitment to the safety and the fuel saving goals. The other half of the sample did not receive any explicit temporal limitations. In order to facilitate the monitoring of fuel consumption, continuous feedback on the amount of fuel available was provided through a display on the dashboard of the simulated vehicle.

We assumed that setting the goal to save as much fuel as possible would motivate drivers to adapt to an eco-driving style. However, we assumed also that drivers in the no-time pressure condition would keep to the fuel saving goal to a greater extent and save more fuel than drivers in the time pressure conditions due to the lack of explicit conflict between fuel and time savings. Therefore we expected that the time pressure group would use more fuel, in total as well as for the urban and rural roads separately (hypothesis 1). Moreover, we also hypothesized that the no time pressure group would perform in a fashion more in accordance with the eco-driving style during interaction situations with other road users than the time pressure group (hypothesis 2). Furthermore, we expected that drivers would prioritize safety goals over time and fuel saving ones in situations of high demand. More specifically, we expected that the no time pressure group would neglect the fuel saving goal, and the time pressure group would neglect both the fuel and time saving goals when handling interactions with other road users (hypothesis 3). In relation to the third hypothesis, we expect shorter safety margins (i.e. later pedal responses) from the time pressure group in the interaction situations because of the prominence of the time saving goal. But because the current study made these interactions also safety critical, the expected effect on safety margins would disappear or be reduced due to the prominence of the safety goal. We will also explore whether fuel feedback aids drivers' behavioral adaptation to save fuel.

2. Method

2.1. Participants

Thirty-six first-year students (16 males) at the Psychology Department of the University of Groningen participated in the study in return for course credits. Participants had held a valid B-class drivers license for an average of 36 months (Min = 11, Max = 170). The mean age of participants was 21 years (Min = 19, Max = 32) and their mean lifetime mileage was 21,100 km (Min = 1800, Max = 75,000).

2.2. Driving simulator

Drivers were tested in a STSoftware driving simulator at the Psychology Department of the University of Groningen. The simulator uses a mockup of a VW Golf cabin and 3 × 42" plasma displays to provide participants with a 210° display of the road environment. The road and traffic scene was displayed at 60 Hz refresh rate (see

Van Winsum and Van Wolfelaar, 1993 for further details). Drivers could control the gas pedal, brake pedal, clutch, gears, steering wheel, and the indicators. The behavior of other traffic participants was controlled by means of generic and specific scenario scripts. In this way we ensured that every participant was presented with the same standard traffic situations. The simulator has been proven to be a valid tool for driving behavior research (e.g. Brookhuis and de Waard, 2010).

2.3. Eco-driving

Ericsson (2001) identified acceleration, deceleration, speed, and gear change behavior as the main indicators of an eco-driving style. Besides these factors, Beusen et al. (2009) included coasting distance, i.e. the distance drivers let the car roll without pressing the gas or brake pedals in their analyses. As such we selected two interaction situations that would require the drivers to perform the aforementioned eco-driving task components; stopping for a traffic light turning red on approach and gap acceptance in a T-intersection with a traffic flow from the right and left. Speed, gear use and pedal use were included as indicators of an eco-driving style. These dependent variables are further explained in Section 2.5.1.1. Additionally, fuel consumption was measured and recorded for the whole drive, as well as for each section, reflecting the overall performance on the fuel saving goal.

2.4. Procedure and design

The procedure consisted of a test drive and an experimental drive. Before starting the experiments, participants drove a trial route of 7 km in a residential area with oncoming traffic in the opposite lane and a speed limit of 50 km/h. During the test drive they practiced several maneuvers that would be required during the experimental drive such as making turns and navigating intersections and traffic lights. The aim was to get participants familiarized with the driving simulator and to detect simulation sickness.

After completing the trial route all participants then read a text on goal setting. The text included background information stating that the aim of the study was to find out the minimum amount of fuel required to complete the trip. A pilot study found that participants consumed approximately 1 l of fuel to complete the experimental route when they were asked to drive as they would usually do and around .83 l of fuel when they were asked to drive in a fuel-efficient manner. Based on this, participants were told that participants in the pilot study consumed around 1 l of fuel on average to complete the route they were about to drive and that it was possible to reduce fuel consumption by around 17% with when an eco-driving style was adopted. Since we did not want the participants to feel that they would not be able to complete the trip due to running out of fuel participants were told they had 1.1 l of fuel at their disposal for the 18 km route, 10% more than the amount of fuel participants in the pilot study used in the usual driving condition. Participants also were prompted to try to save as much fuel as possible. The extra 10% of fuel was excluded from later analyses in order to report the percentage of the fuel saved out of 1 l of fuel. Participants were also told that the car would stop when they consumed all the fuel in the gas tank.

Next, the time pressure manipulation was introduced to half the participants, selected at random. Participants in the no time pressure group read that they had no time constraints and they could take as much time as they wished to make the trip. Conversely, participants in the time pressure group were told to imagine that they were late for a meeting. Thus the no time pressure group was explicitly set the fuel saving goal in addition to the implicit safety goal. The time pressure group had the safety goal, the fuel saving goal, and the goal of meeting temporal limitations; i.e. time saving goal.

The time pressure group (TP) and the no time pressure group (NTP) were equivalent on license duration, $t(34) = .33, p = .75$ ($M_{TP} = 40.65$, $SD_{TP} = 36.20$; $M_{NTP} = 37.77$, $SD_{NTP} = 12.87$), and mileage since licensure, $t(34) = .19, p = .85$ ($M_{TP} = 21,783$, $SD_{TP} = 24,111$; $M_{NTP} = 20,416$, $SD_{NTP} = 19,767$).

Participants then took part in the experimental drive during which they drove through two villages (urban traffic environments), where the speed limit was 50 km/h, and two sections of rural roads, where the speed limit was 80 km/h. Participants were instructed to keep to the speed limits and obey all of the traffic rules and traffic signs. The drive on the rural roads did not involve any critical events and contained several curves and oncoming traffic in the opposite lane to avoid monotonous driving. The drives through the urban areas included several demanding situations with other vehicles at intersections. It was expected that the safety goal would be more prominent in these high-demand situations and fuel saving and time saving would be less important. The roads were straight and visibility was clear at all the intersections where a critical situation took place. All the necessary traffic signs such as the speed limit, traffic lights, and give right of way were placed appropriately before the relevant intersections to facilitate the drivers' anticipation of the upcoming situations.

To facilitate high performance on the fuel saving goal, feedback on the amount of fuel available was continuously displayed on the screen with a bar graph divided into 20 intervals. Participants were informed that each interval corresponded to 5% of the total available fuel. At the end of the trial they learnt the percentage of fuel left in the gas tank. This means that the feedback that was given to the participants about the amount of available fuel through the driving session had a different reference point (a percentage of 1.1 l) than the amount of fuel saved during the trip reported in the results section (a percentage of 1 l). Once the experimental drive was over participants answered some manipulation check questions.

Drivers' performance was recorded by the internal camera of the simulator. After the experimental driving session, the recording of the drive was replayed in the simulator and participants were interviewed in order to obtain further in-depth information about their expectations and regulatory actions for each situation. The whole experiment took around 50–60 min.

2.5. Measures

2.5.1. Driver behavior during critical situations in the road environment

2.5.1.1. Traffic light scenario. The traffic light scenario was activated when the driver was 200 m away from the intersection where the traffic light was located. The light was timed to participants initially saw a green light as they were approaching the traffic light, then the green light switched to yellow 3 s before the participant would reach the intersection and stayed yellow for 2 s. Finally the light turned red a second before the intersection and stayed red for 20 s. When the traffic light was red for the participants, traffic from the side roads started to cross the intersection. The average duration of the task from the start of the scenario, 200 m before the intersection, until switching into fourth gear after crossing the intersection was 51 s for the time pressure group and 56 s for the no time pressure group.

The measurement of dependent variables for the traffic light scenario was split into two sections: the approach to the traffic light and the drive away from the traffic light once the green signal was redisplayed. The start point of the approach data block was 200 m before the intersection, because that was the start point of the scenario, with the end point occurring 10 m before the intersection where the traffic light was located. To prevent data loss, if a participant stopped earlier than 10 m from the intersection, the end point of the data block was marked as the point where the partic-

ipant's velocity reached zero. Velocity and speed change (average deceleration and acceleration) were recorded as the speed-related dependent variables; average rpm was recorded as the gear-use-related dependent variable; and maximum and the average extent of brake and gas pedal push were recorded as the pedal-use-related dependent variables during both sections of the traffic light scenario. The variables for pedal push, either gas pedal or brake pedal, indicated the extent to which the pedal was pushed and was measured in terms of a percentage. The maximum pedal push indicates the furthest extent of the pedal push while the average pedal push indicates the extent of pedal push within a selected range of road section, such as while approaching a traffic light. In addition the gas pedal release distance and brake pedal push distance were recorded as indicators of discrete decisions to take regulatory actions in reaction to the upcoming critical situation. Gas pedal release distance was taken as the distance between the point where the gas pedal was first released and the traffic light. The brake pedal push distance was taken as the distance between the point where the brake pedal was first pushed and the traffic light. Finally, the average amount of fuel used during the approach to the intersection was recorded.

For the drive away behavior, the focus was on gear use to determine the starting and the ending of driving away maneuver. The start point of the data block was the first moment of gear activity while the end point was the moment participants shifted into fourth gear. The fourth gear was chosen because with new cars, such as the one simulated in this experiment, the safe and appropriate gear to obtain fuel-efficiency while driving around 50 km/h is the fourth gear (Kroon, 2006).¹ Driving in fourth gear was also the general course of action we observed among the participants while in the residential environment. Furthermore, when the velocity graphs were examined reaching fourth gear corresponded to the point where the participants started to maintain a steady velocity. Average fuel consumption from the traffic light until the gear shift into fourth gear was recorded along with the dependent variables related to speed, gear use and pedal use mentioned for the traffic light approach section. Participants who violated the traffic light and those who did not shift up to fourth gear following while driving away from the traffic light were excluded, which left 19 participants (10 from the no time pressure group) for the analyses of the traffic light scenario.

2.5.1.2. Gap acceptance scenario. Similar to the traffic light scenario, the approach and drive away behaviors in the gap acceptance task were analyzed separately. Unlike the traffic light scenario, the gap acceptance scenario did not have easily defined start and end points. The scenario within the simulator software started when the participant was 250 m away from the intersection. However the appearance of the cars to the participants depended on the speed of the participant and corresponded to different times and distances for each participant. Thus, it was not possible to set specific distances as data markers. Instead, speed regulation was adopted as the criterion. The start marker was the moment drivers took regulatory action by starting to release the gas pedal, while the end marker was when the participants reached a velocity of zero. The duration of the gap acceptance task from the start of the scenario until the participants switched into the fourth gear after crossing the intersection, including the time spent waiting for an appropriate gap, was on average 35 s for both the time pressure and the no time pressure groups.

For the drive away from the intersection, the criteria for data markers were the same as in the traffic light scenario, i.e. the start marker was the first gas pedal push and end marker was shifting into fourth gear. Eight participants (5 from the no time pressure group) did not shift into the fourth gear after the intersection, so only the data for the remaining 28 participants (13 from the no time pressure group) was analyzed. The dependent variables for performance while approaching the intersection and while driving away from the intersection were the same as those analyzed in the traffic light scenario.

2.5.2. Manipulation check

After the experiment participants were asked several questions about whether they experienced time pressure and if they believed they could have saved more fuel if they had had more time on a 5-point scale (1 “not agree at all”, 5 “totally agree”). Significant differences between the time pressure and no-time pressure groups would therefore indicate that the manipulation to induce time pressure was successful.

2.5.3. Verbal reports

The aim of the verbal reports was to complement the behavioral data by providing information on the reasoning behind participants' regulatory actions. Including the type of information drivers reported taking into account when handling the critical situations at the intersections, which goals they stated were prominent during their actions and how much they used the fuel consumption feedback provided (Saad, 2002). As such, participants were asked several questions for each traffic situation after the video replay of each critical situation was displayed.

The replay of each critical situation was replayed to the participants in two parts. First, the video was stopped as situation was evolving. For instance, in the traffic light situation, the video was stopped before the light turned yellow. Similarly in the gap acceptance situation, the video was stopped when the yield sign was visible but before the cars appeared at the intersection. At this point participants were asked what they had anticipated in that particular situation and what they had thought they should do to manage the situation. Then, the video was started again. At the end of the interaction situation the recording was stopped and participants were asked to describe their behavior and if they had thought of any other behaviors they could have performed. Finally, participants were asked if they explicitly aimed to save fuel and if they monitored the feedback bar while they were approaching the critical situations.

3. Results

3.1. Time pressure manipulation check

Participants in the time pressure group reported experiencing higher time pressure during the drive than those in the no time pressure group, $t(34) = 4.31$, $p < .001$ ($M_{NTP} = 1.55$, $SD_{NTP} = .78$; $M_{TP} = 2.83$, $SD_{TP} = .98$). Additionally participants in the time pressure group believed that they could have saved more fuel if they had had more time, $t(34) = 3.20$, $p = .003$ ($M_{NTP} = 1.61$, $SD_{NTP} = .97$; $M_{TP} = 2.94$, $SD_{TP} = 1.47$). The duration of the trip was also different between the groups, with the time pressure group completing the trip in a shorter time, $t(34) = -3.23$, $p = .003$ ($M_{NTP} = 20.06$, $SD_{NTP} = 1.57$; $M_{TP} = 18.47$, $SD_{TP} = 1.25$). These results suggest that the manipulation to induce time pressure was effective.

3.2. Total fuel saved during the trip

In order to test the first hypothesis, we compared participants' performance on the fuel saving goal. As expected, fuel saving was

¹ We controlled the raw data for each participant in order to avoid data loss due to not switching into the fourth gear. In the traffic light scenario two participants and in the gap acceptance scenario four participants were excluded due to our data sampling criterion.

Fig. 1. Means and standard errors of the amount of fuel saved by the time pressure and the no time pressure groups.

higher among the no time pressure participants than the time pressure participants, $F(1, 34) = 8.38, p = .007$ (see Fig. 1). A similar effect was observed when the fuel consumption on the urban and on the rural roads was analyzed separately. With the no time pressure participants consuming less fuel than the time pressure participants on both the urban, $F(1, 34) = 7.88, p = .008$, and the rural roads, $F(1, 34) = 7.43, p = .010$ (see Fig. 2). Thus, fuel saving was higher for the no time pressure group for the entire trip and for the different road environments separately.

Drivers' verbal reports on the overall trip revealed an interesting finding about the monitoring of the fuel level feedback throughout the experimental drive. With the majority of the participants in both groups reporting that their driving style was most directed by a fuel saving goal while driving on the rural roads rather than on the urban roads. A particularly common comment was that it was difficult to pay attention to the feedback on the amount of the fuel available and to drive fuel-efficiently while also paying attention to possible interactions with other road users in the urban areas.

3.3. Effects on indicators of an eco-driving style: the traffic light scenario

3.3.1. Behavioral analyses

To test hypothesis 2, first, we examined participants' behavior while approaching the intersection where the traffic light scenario took place. An independent t -test analysis was carried out to compare the performance of the two groups on the main indicators of an eco-driving style mentioned in Section 2.5.1.1. Table 1 shows the means, standard deviations, t -test coefficients, and p -values for the performance variables recorded while approaching the traffic light. The two groups differed mainly on speed-related variables that affect fuel consumption. More specifically, participants in the no time pressure group drove slower, at a lower rpm, and had lower average fuel consumption compared to the time pressure group, although the last result was marginally significant. There was no significant difference between the groups in deceleration or braking.

Fig. 2. Means and the standard errors of the amount of fuel used by the time pressure and the no time pressure groups in different road environments.

Based on the third hypothesis, we also expected that the time pressure group would respond later than the no time pressure group only when the time saving goal was prominent. Participants in the time pressure group had a longer gas pedal release distance and brake pedal push distance than the participants in the no time pressure group but this difference was only marginally significant. Considering that the participants in the time pressure group might have released the gas pedal and braked earlier because they were driving at a higher speed, we conducted a univariate ANCOVA with the average velocity as a covariate. In this case, the marginal difference between the groups in terms of gas pedal release distance reached significance, $F(1, 16) = 4.54, p = .049$, whereas the difference in brake distance did not $F(1, 16) = 3.36, p = .085$. Additionally, the groups were similar on coasting distance, $F(1, 16) = 2.13, p = .164$ ($M_{TP} = 22.91, SD_{TP} = 17.36$; $M_{NTP} = 16.88, SD_{NTP} = 12.20$). The pattern the results therefore suggests is that the performance and regulatory behaviors while approaching the traffic light were in line with participants acting with a safety goal in mind.

Secondly, we examined drivers' behavior while they drove away after the traffic light returned green. Similar to the approach behavior, independent t -test analysis was conducted to compare the groups. Table 2 shows the means, standard deviations, t -test coefficients, and p -values of the performance variables recorded while driving away from the traffic light. In line with the second hypothesis, participants in the no time pressure group drove slower overall, had a more gradual acceleration, a lower gas pedal push, and lower fuel consumption when compared to the time pressure group. We did not observe significant differences between the groups in rpm or gear shift distance.

3.3.2. Verbal reports

We analyzed participants' verbal reports following the experimental drive by focusing on two issues: drivers' expectation of the developing situation and the role of their goals and feedback in their regulatory actions. The subsequent analysis of the verbal reports suggest that the participants decision criteria for regulatory actions during the critical situations were based on the safety margins such as the distance from the traffic light, their approach speed, and the period that the traffic light had already been green, as well as the anticipated consequences of their regulatory actions (e.g. "I wouldn't be able to stop at that speed if I had braked slowly. So I had to brake abruptly"). All participants expected the light to turn red when they reached the intersection because it had stayed green for a long time already. Despite anticipating that they would have to slow down, only three participants reported releasing the gas pedal when the traffic light was green. The majority of the participants instead reported releasing the gas pedal when the traffic light turned yellow, or in other words when they became sure that they would have to stop. When asked whether they had thought of any alternative reactions, the majority reported that they had not, and that they would probably have reacted in the same way if they encountered the same situation again.

The results in relation to the second and third hypotheses about the effect of the fuel saving goal on the regulatory actions revealed that the majority of the participants (6 in the time pressure group, 7 in the no time pressure group out of 19 for the traffic light scenario) said that their actions were not directed by the fuel saving goal while approaching the traffic light. Also the majority of the participants in both groups reported that they were concerned more with handling the situation safely than with driving fuel-efficiently (e.g. "I was more concerned about a possible accident"). Indeed, some of them reported forgetting the fuel saving goal (e.g. "I [only] remembered about fuel saving only after braking so rapidly, just before the traffic light"). Similarly, the majority of the participants reported that they did not check the fuel feedback information while they were approaching the traffic light.

Table 1
Means, standard deviations, *t*-values, and *p*-values for behavioral indicators of an eco-driving style while approaching the traffic light for the time pressure (TP) and the no time pressure (NTP) groups.

	TP M (SD)	No-TP M (SD)	<i>t</i>	<i>p</i>
Velocity (m/s)	16.01 (1.70)58 km/h	14.10 (.82)51 km/h	3.18	.006
Average rpm	1455 (176)	1232 (111)	3.32	.004
Average fuel (l)	.032 (.010)	.025 (.006)	1.94	.069
Deceleration (m/s ²)	-.95 (.34)	-.76 (.16)	-1.54	ns
Maximum brake push (%)	92.68 (7.56)	96.15 (5.12)	-1.18	ns
Average brake push (%)	12.11 (5.52)	9.90 (2.37)	1.16	ns
Gas pedal release distance (m)	61.61 (12.71)	51.37 (12.03)	1.81	.089
Brake pedal push distance (m)	39.70 (5.72)	34.49 (2.93)	2.05	.056

Note: ns means $p > .10$.

3.4. Effects on indicators of an eco-driving style: the gap acceptance scenario

3.4.1. Behavioral analyses

To test hypothesis 2 for the gap acceptance task, first, independent *t*-test analyses were conducted to examine eco-driving performance while approaching the intersection. Table 3 shows the means, standard deviations, and *t*-test values for the two groups' performance as they approach the intersection. Participants in the time pressure group drove faster than those in the no time pressure groups. However, the time pressure participants did not have a significantly higher average level of fuel consumption than those in the no time pressure group. The participants in the time pressure group did brake more than those in the no time pressure group, but this was marginally significant. There were also no significant differences between the groups in deceleration or rpm. With respect to the third hypothesis, there were no significant differences between the groups on gas pedal release distance and brake pedal push distance. Interestingly, the mean values for gas pedal release distance for both groups corresponded to the appearance of cars in the intersection. This indicates that participants' initial response to the oncoming cars was releasing the gas pedal regardless of whether they were in a hurry or not.

Next, we investigated participants' behavior as they drove away after the gap acceptance task. The groups were compared using independent *t*-test analyses. During the drive away, the two groups significantly differed only on instantaneous fuel use, with the time pressure group participants using more fuel than the no time pressure group participants, $t(26) = 2.15$, $p = .042$ ($M_{TP} = .14$, $SD_{TP} = .05$; $M_{NTP} = .10$, $SD_{NTP} = .04$). There were no significant differences between the groups for any of the other indicators.

3.4.2. Verbal reports

The behavioral data indicated that the majority of the participants released the gas pedal around the same distance. Consistent with this finding, most participants after watching the replay reported that they released the gas pedal as soon as the cars became visible at the intersection. Therefore the critical factor for the par-

ticipants was not the yield sign but the vehicles in the intersection. Similarly to the traffic light situation, participants also reported they did not consider any alternative reactions to the developing situation.

Twenty-two participants of the 28 analyzed for the gap acceptance situation reported that they were not thinking of the fuel saving goal while approaching the interaction situation. This is consistent with the third hypothesis and similar to the traffic light scenario, with the majority of the participants' reporting that they focused on safe performance (e.g. "I was more worried about crossing the intersection safely") rather than the fuel saving goal once they detected that a potential conflict situation was evolving. Furthermore, the majority of the participants reported that they were not paying attention to the fuel use feedback while they were approaching the interaction (e.g. "I was not checking the bar when I was approaching the intersection but I thought that I was consuming fuel when I was waiting to cross"). Several participants had statements which explicitly indicated attempts to compromise between different goals like "I had to cross the intersection, on the one hand, and had to save fuel, on the other. [So] I had to find a middle way".

4. Discussion

The current study investigated drivers' behavioral adaptation when balancing multiple goals under different task loads. Starting from the assumption that all drivers consider the safety goal when driving we also set fuel saving as a strategic goal to motivate drivers to adopt a fuel-efficient driving style. In addition, time pressure was placed on half of the participants. This resulted in one group which had to only consider the extra goal of fuel saving, while the other group had to consider both the extra fuel and time saving goals. Driving performance was monitored for the complete trip and for specific critical situations. Our main interest was how drivers adapted their behavior to multiple goals in low and high demanding situations and which goal was prioritized. We also explored whether feedback on fuel consumption facilitated adaptive behavior for the fuel saving goal.

Table 2
Means, standard deviations, *t*-values, and *p*-values for behavioral indicators of an eco-driving style while driving away from the traffic light for the time pressure (TP) and the no time pressure (NTP) groups.

	TP M (SD)	NTP M (SD)	<i>t</i>	<i>p</i>
Velocity (m/s)	14.32 (2.02)52 km/h	12.11 (2.02)44 km/h	2.38	.029
Average rpm	1654 (292)	1480 (219)	1.48	ns
Average fuel (l)	.060 (.020)	.043 (.009)	2.39	.029
Maximum gas pedal push (%)	60.03 (17.65)	43.72 (13.52)	2.28	.036
Average gas pedal push (%)	31.12 (6.46)	22.99 (3.14)	3.55	.002
Acceleration (m/s ²)	.92 (.37)	.56 (.18)	2.74	.014
Gear shift distance (m)	102.40 (50.06)	115.47 (46.21)	-.590	ns

Note: ns means $p > .10$.

Table 3

Means, standard deviations, *t*-values, and *p*-values for behavioral indicators of an eco-driving style while approaching the gap acceptance intersection for the time pressure (TP) and the no time pressure (NTP) groups.

	TP M (SD)	NTP M (SD)	<i>t</i>	<i>p</i>
Velocity (m/s)	16.39 (1.39)59 km/h	14.89 (1.44)53 km/h	2.80	.001
Average rpm	1021 (116)	1004 (122)	0.39	ns
Average fuel (l)	.009 (.002)	.008 (.005)	0.83	ns
Deceleration (m/s ²)	−1.50 (.82)	−1.32 (.65)	−0.63	ns
Maximum brake push (%)	87.40 (18.29)	70.66 (29.13)	1.85	.076
Average brake push (%)	18.14 (10.74)	18.17 (15.66)	.995	ns
Gas pedal release distance (m)	100.81 (27.97)	105.80 (28.33)	−0.47	ns
Brake pedal push distance (m)	55.07 (18.33)	49.58 (18.42)	0.79	ns

Note: ns means $p > .10$.

As expected, the overall fuel saving was higher for the no time pressure group than for the time pressure group. The amount of fuel saved by the no time pressure group (around 10%) was similar to that reported by studies on the average effects of eco-driving training in real world situations (as cited in [Barkenbus, 2010](#)). The time pressure group on the other hand had a fuel saving of only 2%. The difference in fuel saving between the time pressure groups was also consistent across both the urban and rural settings. Consistent with the first hypothesis, the no time pressure group saved more fuel than the time pressure group in the urban as well as the rural road segments. Thus, we can conclude that overall, the participants in the no time pressure group kept better to the fuel saving goal than the participants in the time pressure group.

For the critical situations we obtained somewhat different results. Consistent with our expectations, we observed differences between the two groups in terms of speed-related indicators of eco-driving such as fuel consumption and rpm, particularly for the traffic light scenario. However, there were no differences in regulatory actions such as speed change related to fuel saving in either group. Therefore, the second hypothesis was only partly supported. We did find differences between the time pressure and no time pressure groups in pedal use, which can also be interpreted as related to speed. The groups were similar in terms of deceleration and acceleration, in both the interaction situations. However, participants in the time pressure group released the gas pedal and started braking slightly earlier than the no time pressure group during the traffic light interaction, although this difference was marginally significant. Based on these findings we can conclude that the regulatory behaviors of all participants during the critical situations indicate that, in line with the third hypothesis, drivers' regulatory actions in conflict situations seem to be particularly directed by safety-oriented goals, even when they have to manage several other conflicting goals.

The verbal reports also suggest that the participants varied the importance of the competing goals based on the different road situations and task demand they encountered. As we assumed, safety goals seemed to remain focal throughout the drive. Also participants did report that they tried to adapt their driving style to drive fuel-efficiently mainly when they were driving on the rural roads. However, in the urban areas the safety goal became more prominent because they had to pay attention to the more complex traffic environment. This is consistent with research from [Cnossen et al. \(2000\)](#) who also found that drivers give priority to the goals of driving safely over any additional non-driving goals in high demand situations. In the current study, we found this also to be the case even when the additional goal is driving-related and could be realized by adapting one's driving style.

Furthermore, the results indicate that drivers in the time pressure group saved almost no fuel and completed the trip in a shorter time than the participants in the no time pressure group. This suggests that the former group was strongly motivated by the time saving goal at the cost of the fuel saving goal. This is of note, as we

did not use a very strong manipulation to induce time pressure such as setting a specific time limit to complete the trip or using a timer to indicate time running. Instead we only asked the participants to imagine that they are in a hurry. So even with a weak induction participants still seemed to give priority to saving time rather than to saving fuel. This is likely to be because saving time can be considered as a natural and immediate goal for drivers in many situations, whereas explicitly aiming to save fuel because of ecological considerations is a relatively new goal for drivers. Therefore, it may take time before drivers can internalize the fuel saving goal, integrate fuel saving as part of the driving task in their mental representations, and learn to assign a high utility to fuel saving goal. However, based on the current findings, we can speculate that fuel saving does not fulfill the aspiration level to compete with other goals of driving such as time saving and therefore may be abandoned easily by drivers as situations change. Additionally, we can reason that fuel saving did not become a decision criterion to guide drivers' actions during negotiations of interactions with other road users such as handling a gap acceptance task, or drivers' performance in demanding road environments such as driving in an ordinary urban area. This result has important implications for eco-driving training and will be discussed below.

The verbal reports also revealed that the use of fuel feedback for behavioral adaptation depended on the situational demands imposed by the road and traffic conditions. For instance participants reported not paying attention to the fuel saving goal or the feedback during the critical situations or on the urban roads. This suggests that the feedback was ignored when the situational demands were high. However, previous research on eco-driving has shown that drivers do benefit from in-vehicle feedback systems in reducing fuel consumption (e.g. [Hallihan et al., 2011](#); [Barkenbus, 2010](#)). The current study therefore complements these findings by specifying that certain task conditions that influence drivers' attentiveness to and negligence of fuel feedback systems in demanding situations. Based on drivers' verbal reports, we can also conclude that while the traffic environment made a difference in terms of feedback processing, having a time limitation did not.

Our results could be taken as suggesting that mental workload plays a role in drivers' adaptation of their driving style to meet multiple strategic goals during driving. With the majority of the participants reporting that they were not acting in order to fulfill the fuel saving goal during demanding situations such as the interaction situations and driving through the urban area. However, in this study we did not explicitly measure mental workload, instead inferred it from verbal reports; therefore, future research should test the role of mental workload more directly.

Another important direction for further research is the replication of our findings in real life. In particular, distance estimation in a driving simulator can be difficult for drivers. However, the dynamics of on-road research make the control of external factors, task demand factors, and the monitoring of goal prioritization more challenging, and potentially risky.

The current results can be seen as having theoretical implications for drivers' possible goal hierarchy, with the priority of different goals changing at the different task levels that are theorized to make up the driving task. For instance, although fuel saving can be a dominant goal at the strategic level, it may be pushed to background at the maneuvering level, especially when the task demands are high and other goals are prioritized (cf. [Lindenberg and Steg, 2007](#)). It seems that the deciding factor for which goal is prioritized depends highly on the situation. Future research should study how and which contextual factors influence the prominence of different goals of driving and regulatory actions to prioritize goals within the driving task hierarchy.

In particular, our findings may have important implications for eco-driving training programs. Since our current results suggest that eco-driving goals are likely to conflict with other goals such as time saving, which appears to be a much stronger motivating factor. Indeed, a recent study indicated that drivers consistently overestimate the amount of time they could save by increasing their speed, which may help to partly explain why time saving is so strongly valued ([Svenson, 2008](#)). Eco-driving campaigns and eco-driving trainings can emphasize this point further in order to convince drivers that an eco-driving style does not have to have a significantly negative impact on travel time. Policy makers in particular have set an aim for a 10% reduction in fuel consumption in the long run by means of fuel-efficient driving style ([White Paper, 2001](#)). However, a one-day eco-driving training program targeting experienced drivers resulted in a reduction in fuel consumption of only 5–2% one year after the training ([Beusen et al., 2009](#); [af Wahlberg, 2007](#)). It may be that eco-driving training programs are more effective when a more extensive program is followed in order to make eco-driving a part of drivers habitual, automated driving, and more work on these types of long term training programs should be encouraged. Furthermore, in order to tackle the challenge of managing critical situations, training programs could give a higher emphasis in the training of eco-efficient driving skills in such high demanding situations. However these critical situations do only make up a small percentage of regular driving, and tend to be safety critical situations of short duration. Therefore it may be more worth while for eco-driving to only concentrate on periods outside of these critical situations where drivers have greater time, and inclination, to drive in an eco-friendly manner.

5. Limitations

In their naturalistic driving environment drivers have various and sometimes even competing goals. However in the current study we only explicitly focused on three goals: fuel saving, time saving, and safety. Future research could expand the current study by focusing on different types of goals. Furthermore, past research shows that driver's level of familiarity with the route network influence choice of the strategy in time management such as travelling alternative routes or adjusting the time of leave (e.g. [Hamed and Abdul-Hussain, 2001](#)), which eventually have consequences for fuel consumption. Such an option was not available in this study, since all participants were required to follow the same route in order to maximize experimental control. However, driver's familiarity with the road network could perhaps be taken into account in future research. Also, replicating the study with a more experienced driver sample could yield more reliable results for the generalizability to the larger driver population.

Verbal reports were used to investigate the subjective experiences of drivers with respect to behavioral regulation which provided great insight to drivers' goal prioritization in regulatory actions. However this approach does somewhat lack structure. Therefore, based on the current results, a structured instrument

could be developed to study more systematically to enrich our knowledge on goal prioritization and decision making processes in drivers' self-regulatory behavior.

6. Conclusion

The current study showed that drivers were less able to keep to an eco-driving style when the traffic environment is highly demanding, particularly in residential areas and during critical situations. Additionally, time pressure inhibited performance on the goal to drive in a fuel efficient manner. This suggests that eco-driving goals are easily pushed to the background when they conflict with other goals, particularly goals related to safety and time saving.

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