Transportation Research Part F 81 (2021) 1–13

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

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

Effect of multiple traffic information sources on route choice: A driving simulator study

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ARTICLE INFO

Keywords:
Advanced traveller information systems
Route choice behaviour
Driving simulator
Conflicting information
Compliance

ABSTRACT

With the arrival of new technologies more en-route traffic information sources have become available, especially in-car information sources. The aim of this study is to gain more insight into the effect of multiple, and possibly conflicting, sources of information on route choice and driver behaviour. In a driving simulator experiment, participants were required to make multiple drives, each of which ended with a choice between the normal and an alternative route. On each trial participants received traffic information from a Variable Message Sign (VMS), i.e. a dynamic sign above the road providing descriptive traffic information in the form of expected travel times (ETTs), a navigation device providing in-car prescriptive route advice, or information from both sources. In the latter type of trial the information could be congruent or conflicting with regards to ETTs on the VMS and advise from the navigation. After each trial, participants indicated how much trust they had in the traffic information and their primary information source. A Bayesian model was used to quantify the propensity to switch to the alternative route. Results indicate that overall compliance was very high for the primary source even when the other source did not corroborate this information and that most participants preferred to use the information from a VMS. However, when both the VMS and the navigation device provided information and the VMS indicated the same ETTs for the normal and alternative route, route choice was influenced by the advice provided by the navigation device. Also, in this type of trial mean speed was significantly lower compared to trials in which the two sources were in conflict, indicating increased mental workload, most likely due to attentional dissonance: a situation in which stimuli compete for attention resulting in cognitive conflict and the need to inhibit non-relevant information. A deeper understanding of how drivers use multiple traffic information sources and cope with irrelevant information could support driver safety and comfort, increase the usability of information sources, and help reduce stress, anxiety, and information overload while driving.

1. Introduction

With the rapid rise of urbanization and motorization congestion problems are set to grow in the upcoming years. Advanced traveller information systems (ATIS), providing travellers with travel information such as for example incident locations, prevailing

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https://doi.org/10.1016/j.trf.2021.05.008
Received 6 March 2020; Received in revised form 4 May 2021; Accepted 16 May 2021

traffic conditions and optimal routes, are thought to help ease these congestion conditions (Zhong, Zhou, Ma, & Jia, 2012). With the arrival of new technologies the availability and diversity of ATIS have rapidly increased (Ben-Elia & Avineri, 2015).

This increased availability of various types and sources of traffic information can either support or hinder drivers in their route choice decision process. Supporting traffic information enables drivers to make more informed decisions with respect to for example departure time and route choice (Toledo & Beinhaker, 2006), and it can improve driver comfort and reduce stress (Adler, 2001; Balakrishna, Ben-Akiva, Bottom, & Gao, 2013; Chatterjee & Mcdonald, 2004; Lyons, 2006). On the other hand, with an increasing amount of traffic information drivers may experience information overload (Ben-Elia & Avineri, 2015) and attentional dissonance, which occurs when stimuli compete for attention, possibly resulting in cognitive conflicts (Nilsson, Mullaart, Strand, & Eriksson, 2020). This in turn can lead to worse driver performance and to unsafe driving especially when the driver is distracted by an abundance of (conflicting) information (Matthews et al., 1998; Matthews, 2002; Nilsson et al., 2020).

The current study investigates the effects of multiple sources of traffic information, specifically when these are conflicting or congruent, on route choice decisions and driver performance. In a driving simulator experiment participants made short drives, resulting in a route choice between a normal and an alternative route. During these drives participants were provided with roadside descriptive traffic information on a VMS, in-car prescriptive advice from a navigation device, or information from both. In trials where both sources provided traffic information, the information could either be congruent or conflicting. To our knowledge this is the first driving simulator study that examined the interaction between various traffic information sources and how information congruency of these information sources influences route choices and driving performance. The current study is important, as more and more sources of information will become available to the driver and effects of this increase on route choice and driver performance is yet unknown.

The effectiveness of traffic information depends on driver compliance. Several studies show that drivers comply more with prescriptive than with descriptive traffic information (Ben-Elia, Di Pace, Bifulco, & Shiftan, 2013; Dia & Panwai, 2007). Also, inaccurate traffic information decreases compliance, and this effect seems to be larger for descriptive than prescriptive information (Ben-Elia et al., 2013). When multiple sources of en-route traffic information are available to the driver, compliance is difficult to predict. When the information sources are congruent, it can reinforce compliance (Kattan, Habib, Tazul, & Shahid, 2011), but when information is conflicting, drivers are less likely to trust the information provided (Ben-Elia & Avineri, 2015) resulting in a reduced compliance. Because traffic information systems develop further from descriptive roadside systems to more personalised and prescriptive in-car systems (Ben-Elia & Avineri, 2015) it is important to compare the effects of prescriptive and descriptive information sources on route choice.

Typically research into en-route choice decision-making is conducted using stated preference methods (Xuan & Kanafani, 2014). An advantage of investigating route choice in driving simulator experiments and in field studies is that traveller's actual behaviour can be captured (see for example Ardeshiri, Jeihani, & Peeta, 2015; Xuan & Kanafani, 2014; Wilmink, Jonkers, Snelder, & Klunder, 2017; Romero, Gomez, Rangel, Jurado-Piña, & Vassallo, 2020). Driving simulators, furthermore, allow precise control over the experimental conditions and traffic conditions to which the participant is exposed and driving performance and behaviour data can be studied accurately (Yan & Wu, 2014). This is important because an increase of traffic information messages can induce an increased cognitive workload, which in turn can lead to degraded driver performance (Blanco, Biever, Gallagher, & Dingus, 2006; Matthews, 2002) and simplified decision-making strategies (Katsikopoulos, Duse-Anthony, Fisher, & Duffy, 2000). The current driving simulator experiment was designed to study the effects of multiple sources of traffic information on both route choice and driver performance.

Recent driving simulator studies investigating the use of VMSs or navigation systems mainly examine usability factors such as for example placement and content format, and their effect on driving performance and safety, and to a lesser extend route choice (see for example Pankok & Kaber, 2018; Yared & Patterson, 2020; Xu, Wu, Rong, & Peng, 2020). However, a few recent driving simulator studies do include results related to route choice. Yan and Wu (2014) conclude that on a VMS, graphical information has more effect on route diversion than textual information (Yan & Wu, 2014). Ardeshiri et al. (2015) show that besides travel-time savings, important factors in compliance with the VMS are the reliability of the information and driver experience. Jeihani, NarooieNezhad, and Kelarestaghi (2017) demonstrate that driver's attitudes and beliefs about the VMS, i.e. VMS reliability and perceived helpfulness, influence compliance, together with a higher exposure to VMSs. In their study participants were also provided with detour signs and a navigation system for rerouting, and it appeared that the availability of a navigation system to support rerouting significantly increased route diversions (Jeihani et al., 2017).

Based on previous findings, we expect that participants who have both sources available will favour and show high compliance with the prescriptive information from the navigation device, compared to the descriptive information from the VMS. In this study compliance was defined as following the advice of the navigation device or adhering to the route with the shortest travel time displayed on the VMS, similar to Bifulco, Di Pace, and Viti (2014). Furthermore, we expect that when the two sources are in conflict with each other, participants trust the information less than when sources are congruent, and possibly experience higher cognitive demands when making a route choice.

To determine how en-route traffic information affects route choice, a Bayesian model was used to quantify the propensity to switch to the alternative route. These switching propensities were then used for further analyses. In the next section the Bayesian model is explained in more detail.

2. Bayesian model

A Bayesian cognitive model was constructed to gain insight in whether and how the tendency to switch routes changed under different traffic information conditions. In this model the switching propensity θ (theta) is the result of how many switches to the alternative route (k) were made, for the total amount of trials (n), in the different conditions (i) of the experiment. In the model the prior distribution, our expectation of the distribution of θ, is updated with the data D, i.e. k and n, from the driving simulator experiment, resulting in a posterior distribution of θ, using the Bayes' rule:

$$p(\theta|D) = \frac{p(D|\theta)p(\theta)}{p(D)}$$

where $p(D)$ ensures that the area under the posterior distribution equals 1. Thus the posterior distribution is a combination of our prior expectation of the distribution of theta, i.e. the switching propensity, and the data from the experiment (Lee & Wagenmakers, 2014).

For this experiment, our prior assumption for the switching propensity θ was that all switching rates between 0 (no switching to alternative route) and 1 (switching to alternative route in all trials) are equally likely, i.e. a Beta(1,1) distribution. This indicates that the effect of the provided information on the route choice and switching was uncertain to us. The Bayesian model was run in WinBugs14 using 10^5 iterations (Lunn, Thomas, Best, & Spiegelhalter, 2000). See Fig. 1 for a graphical representation of the model, using the graphical model notation of Lee and Wagenmakers (2014).

3. Materials and methods

The experiment was approved by the Ethical Committee of TNO (TCPE), adhering to the ethical principles of the WMA Declaration of Helsinki with regards to research involving human subjects.

3.1. Participants

Twenty-four participants (20 men, four women, $M_{\text{age}} = 59$ years, $SD_{\text{age}} = 8.8$) took part in the experiment. All had normal or corrected to normal vision and were in possession of a full driver's license. All participants were experienced drivers and drove more than 10000 km/year ($M_{\text{mileage}} = 19458.3$ km/year, $SD_{\text{mileage}} = 9600.6$). In comparison, their average mileage was around 53 km/day whereas Dutch car drivers on average drive around 12.7–23.5 km/day (Statistics Netherlands, n.d.).

3.2. Apparatus and stimuli

3.2.1. Driving simulator

For the experiment one of the driving simulators of TNO was used. The virtual environment was constructed with software developed by TNO and was displayed on a 32-inch. screen. Participants used a Logitech G27 wheel, gas, brake and shift module to control the simulated car. The navigation device was presented on a 7-inch touch screen on the left side of the steering wheel. Sounds, produced by the simulated car and other traffic, were presented with two speakers at the participant's feet (see Fig. 2).

3.2.2. Simulated environment

From the simulated junction two advised routes leaded to point C, the destination of the participants. The route via the A1 was the fastest (time-wise) and the shortest (distance-wise) when no delays are present. It is denoted in this paper as the normal route, assuming drivers will choose both the shortest and fastest route when possible. The route via the B1/B2, which takes 5 min longer than the route via the A1, when no delays are present, is denoted as the alternative route, see Fig. 3.

The placement of the signage, i.e. directional signage and the VMS, at the simulated junction was based on a prototypical Dutch motorway junction and signage was placed and formatted consistent with Dutch Road Authorities' formats and standards (CROW, 2017). The simulated road was a four-lane motorway. Other traffic was present; traffic in the lane of the participant's vehicle drove the

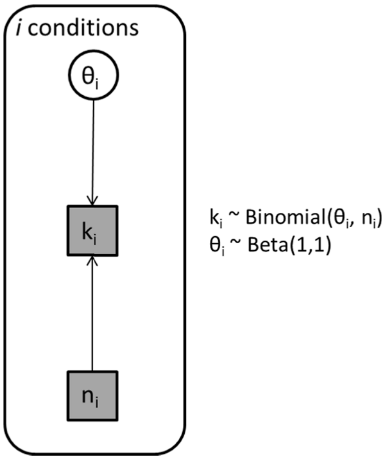

Fig. 1. Graphical representation of the Bayesian switching propensity model.

Fig. 2. Image of the route-choice driving simulator of TNO used in this experiment.

same speed, and other traffic drove 5% faster than the participant. All simulated traffic kept their own lane.

3.2.3. Traffic information

The VMS was situated above the road, 1.5 km before the junction. In trials in which no information on the VMS was shown, the VMS was empty. The simulated navigation device interface was similar to the TomTom® navigation device with live traffic updates often used in the Netherlands (see Fig. 4). In trials with traffic information on the navigation device, this information was shown from the start of trial and for the whole duration of the trial.

3.2.4. Trials

The participant's vehicle was placed two kilometres before the junction, on the rightmost lane, starting with a speed of 120 km/h. Participants drove towards the junction regulating their own speed and lane as they normally would. A route choice was made by choosing one of the two lanes of the A1, or one of the two lanes diverting to the B1/B2. Trials ended after participants had driven 200 m past the last point where they could switch routes. No actual arrival times were provided at the end of the trial: the focus of this study is the inherent preference for the information sources and the relationship between the two sources when the sources were presented together. By not providing actual arrival times the level of trust reported by the participants after each trial reflected these two aspects and was not influenced by actual delays.

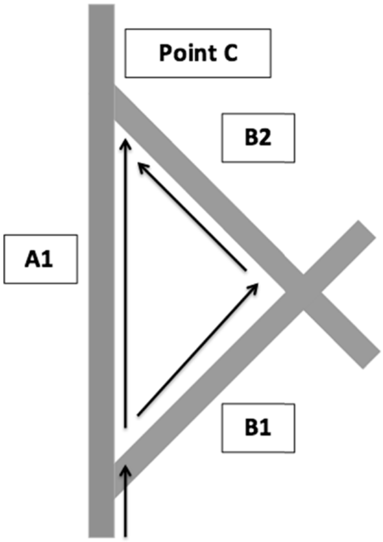

Fig. 3. Graphical representation of the junction simulated in the experiment.

Fig. 4. Example images of the VMS and the navigation device used in the experiment.

3.3. Scenario

Participants were shown the schematic representation of the motorway in Fig. 3 at the beginning of the experiment. They were told to imagine they were driving from home to work at point C, directly next to the exit of the motorway, arriving at their work place at nine o'clock and preferred not to arrive late. They were asked to use the provided traffic information as they normally would and adhere to the road rules.

3.4. Experimental design

The experiment consisted of four blocks: a Control block and three experimental blocks. The Control block consisted of trials in which the route via the A1 was the fastest (time-wise) and the shortest (distance-wise). It was implemented to see if participants actually choose the shortest and fastest route when no delays were present on either route.

In the three experimental blocks the type and number of traffic information sources were varied: participants could receive traffic information from the VMS (VMS block), advice from their navigation device (Navigation block), or information from both sources at the same time (Combination block). Within the blocks two experimental conditions were varied. (1) Expected Travel Times (ETTs): the ETTs for route A1 and B1/B2 were the same (A = B), or the ETT for route A1 was longer (A > B). Note that in the experimental blocks there was always a delay on route A1. (2) Delays on route B1/B2: in half of the trials there was also a delay on route B1/B2, resulting in the No Delay versus Delay conditions respectively. In the Combination block the relationship between the two traffic information sources could be: (a) in conflict: the VMS displayed route B having a shorter ETT, and the navigation device advised to continue via route A; (b) congruent: the VMS displayed route B having the shortest ETT and the navigation device advised to divert to route B as well; or (c) complementary: the VMS displayed the same ETT for both routes providing complementary information to the advice provided by the navigation device, i.e. either to divert or continue. Combining these variables resulted in the blocks and trials displayed in Table 1. Trials in the Combination block were performed twice, resulting in 27 trials per participant.

Participants always started with the Control block and ended with the Combination block. The order of the VMS and Navigation blocks was counterbalanced between participants. All trials within blocks were also counterbalanced. The reason to always present the Combination block last was that we were concerned that experience with conflicting information would influence future route choices

Table 1
Experimental set-up of the trials and the relationships between the information sources when multiple sources are avaible.

Block	Expected Travel Time	Delay on B1/B2	Advice Navigation (ETA)	VMS	Relationship
Control	A < B	No Delay	–	–	–
Control	A < B	No Delay	Continue (9:00)	–	–
Control	A < B	No Delay	Continue (9:00)	A:18 | B:23	Congruent
VMS	A = B	No Delay	–	A:18 + 5 | B:23	–
VMS	A > B	No Delay	–	A:18 + 10 | B:23	–
VMS	A = B	Delay	–	A:18 + 10 | B:23 + 5	–
VMS	A > B	Delay	–	A:18 + 15 | B:23 + 5	–
Navigation	A = B	No Delay	Continue (9:05)	–	–
Navigation	A > B	No Delay	Divert (9:05)	–	–
Navigation	A = B	Delay	Continue (9:10)	–	–
Navigation	A > B	Delay	Divert (9:10)	–	–
Combination	A = B	No Delay	Continue (9:05)	A:18 + 5 | B:23	Complementary
Combination	A = B	No Delay	Divert (9:05)	A:18 + 5 | B:23	Complementary
Combination	A > B	No Delay	Continue (9:05)	A:18 + 10 | B:23	Conflicting
Combination	A > B	No Delay	Divert (9:05)	A:18 + 10 | B:23	Congruent
Combination	A = B	Delay	Continue (9:10)	A:18 + 10 | B:23 + 5	Complementary
Combination	A = B	Delay	Divert (9:10)	A:18 + 10 | B:23 + 5	Complementary
Combination	A > B	Delay	Continue (9:10)	A:18 + 15 | B:23 + 5	Conflicting
Combination	A > B	Delay	Divert (9:10)	A:18 + 15 | B:23 + 5	Congruent

in the experiment; that is, once participants were exposed to conflicting information from the Combination block, they would regard all information within the experiment with more distrust than they normally would, affecting the way they would interact with this information.

3.5. Procedure

Before the experiment started the experiment and the scenario were explained and participants filled out an informed consent. Participants first drove a number of practice trials to become familiar with the scenario and the driving simulator. The importance of using the en-route traffic information as they normally would was stressed, and the experiment started. After each trial participants could indicate if they needed a short break, and halfway through the experiment a compulsory fifteen-minute break was administered. In total, the experiment, including introduction, briefing and debriefing before and after the experiment, and breaks, lasted around two hours.

After every trial participants had to verbally answer two questions. First, "Which information source provided the decisive information and was the main information source you used to support your route choice decision". Possible answers were "VMS", "Navigation", "Static directional signs above the road", or "Own experience", where "Own experience" refers to the mental representation participants have of the routes leading to their destination. Then participants were asked the question "How much trust do you have in the provided traffic information from the main source you used". Participants indicated their trust on a 9-point Likert-scale with the anchors (translated from Dutch) *A lot of trust, Quite some trust, Not a lot but also not a little trust, A little trust,* and *No trust,* at 1, 3, 5, 7 and 9 points of the scale, respectively. A 9-point scale instead of a 5-point scale was used to capture small differences in levels of trust. Also, the 9-point scale scores better on reliability, validity, and discrimination power between the points than a 5-point scale, and allows participants to express their feeling more accurately (Preston & Colman, 1999).

3.6. Analyses

The Bayesian switching propensity model was applied to the data, resulting in one switching propensity per experimental condition per participant. Also, one switching propensity for the control Block with ETT of A $<$ B was calculated. To analyse differences between the primary information sources, responses were analysed with two Person's chi-square tests (Field, 2009). The first test compared the use of the navigation device and VMS in the single source trials with the multiple source trials of the Combination block. The second test compared the use of the navigation device and the VMS in the three types of information trials in the Combination block. Three parametric Friedman within-subject repeated-measure ANOVAs (Field, 2009) were performed to compare the trust in traffic information between (1) the four blocks, (2) the VMS or the navigation device, and (3) the three types of information trials in the Combination block.

To analyse the route switching propensities derived from the Bayesian model multilevel linear regression models with increasing complexity were compared (Field, Miles, & Field, 2012). The baseline model included the intercept and a variable accounting for the within subject repeated-measure design (Field et al., 2012). The first model included the experimental variables expected travel time (ETT), delay, and block as predictors. The second model included the predictors from the first model with the additional predictors gender, age, and yearly mileage. The third model included the predictors from the first model and the interactions between ETT, delay, and block. Lastly, the fourth model included the predictors from the first model, the socio-demographics from the second model, and the interactions of the third model. The first model was compared to the baseline model. The successive models were compared to the first model, examining if the additional predictors resulted in a significant better model. To analyse the influence of advice from the navigation device and ETTs on route switching propensity, a within-subject repeated-measure 2×2 ANOVA (ETT [A $=$ B, A $>$ B] $\times$ Advice [Continue, Divert]) (Field, 2009) was performed. In analysing the speed behaviour of participants, a within-subject repeated-measure ANOVA (Information type [Congruent, Conflicting, Complementary]) (Field, 2009) was performed using the average speed per trial.

The Person's chi-square tests and the parametric Friedman ANOVAs were performed with R Studio version 1.2.5019 (RStudio Team, 2019) using the stats package (R Core Team (2018), 2018). The comparisons of regression models were also performed with R, version 1.2.5019 (RStudio Team, 2019) using the R packages nlme version 3.1–142 (Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., R Core Team. (2019), 2019) and multcomp version1.4–10 (Hothorn, Bretz, & Westfall, 2008). The ANOVAs where performed with JASP (Team JASP (2016), 2016). All graphs were made using the ggplot2 package version 3.2.1 (Wickham, 2016) in R Studio. Post hoc power analyses using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) indicated sufficient statistical power with the sample size. The observed effect size f is 0.46 for Block, 1.59 for ETT, and 0.34 for Delay with a statistical power of 0.99, 1.00 and 0.89 respectively. The observed effect size for speed is f of 0.39 and a statistical power of 0.99. All statistical powers are well above the recommended 0.80 (Cohen, 1988; Field, 2009).

4. Results

First the results comparing the availability of single and multiple traffic information sources are presented. Then the results from the congruent and conflicting information trials are presented in greater detail.

4.1. *Effects of multiple sources of traffic information*

To analyse the effects of multiple sources of traffic information, trials from the single source blocks, i.e. VMS and Navigation block, were compared to trials of the Combination block. The next sections show the results for the primary source used by participants, the trust in the primary source, and switching propensity.

4.1.1. *Primary source for route choice decision*

The VMS was used significantly more than the navigation device as the primary source to support participant's route choice decisions in both the single source trials and the combination trials, $X^2(1) = 57.05$, $p < .001$, and $X^2(1) = 112.67$, $p < .001$ respectively, see Fig. 5.

4.1.2. *Trust in traffic information sources*

Examining the range of levels of trust within a participant for the four blocks showed that the lowest and highest level of trust differed on average 0.88 ($SD_{Control} = 1.26$) for the Control block, 1.58 ($SD_{Navigation} = 1.72$) for the Navigation block, 1.33 ($SD_{VMS} = 1.05$) for the VMS block, and 2.33 ($SD_{Combination} = 1.13$) for the Combination block. There was a significant difference in average trust in the information sources between the four blocks (Control, VMS, Navigation, Combination), $\chi^2(3) = 20.23$, $p < .001$. Post hoc Wilcoxon sign-tests, (Combination vs. other blocks, and Navigation vs. VMS) using a Bonferroni adjusted alpha level of 0.0125 per test (Field, 2009), indicated that participants had significantly more trust in information in the Combination block compared to both the VMS block ($p = .004$) and the Navigation block ($p = .008$). Examining the range of levels of trust within a participant for the two traffic information sources showed the lowest and highest level of trust differed on average 2.32 ($SD_{VMS} = 1.44$) for the VMS, and 1.60 ($SD_{navigation} = 1.50$) for the navigation device. No significant difference in average trust between the two information sources, VMS and navigation device, was found, $\chi^2(1) = 0$.

4.1.3. *Switching propensities*

As expected, results from the Bayesian model showed a low propensity to switch in the Control block, where there are no delays on the normal route, making it the fastest and shortest route (A < B), see Fig. 6. In analysing the results of the three experimental blocks, the models discussed above were applied, which take into account effects of the variables expected travel time (ETT), and delay on alternative route (Delay), as well as the socio-demographics gender, age, and yearly mileage. Comparison of the outcomes shows that the first model, which includes the experimental variables ETT, Delay, and Block as predictors, had a significant better fit than the baseline model $\chi^2(10) = 81.10$, $p < .001$. The additional predictors socio-demographics age, gender, and yearly mileage, or interactions between the experimental variables did not result in a significantly better fit than the first model: socio-demographics model, $\chi^2(13) = 1.78$, $p = .62$, interaction model, $\chi^2(17) = 5.58$, $p = .59$, socio-demographics and interaction model, $\chi^2(18) = 4.18$, $p = .84$.

As shown in Table 2, fitting the first model revealed significant effects of ETT, Delay, and Block on route switching propensity; see also Fig. 6. As can be expected, route switching propensity increased when the ETT is longer on the normal route than the alternative route, $b = 0.41$, $t(71) = 9.56$, $p < .001$. It also increased when there is both a delay on the normal route and on the alternative route compared to only a delay on the normal route, $b = 0.044$, $t(143) = 2.69$, $p = .008$. Lastly, it appeared that the traffic information source available to the participant influenced the switching propensity. Receiving information from only the navigation device (Navigation block) yielded significantly lower route switching propensities than receiving information from both the VMS and the navigation device (Combination block), $b = -0.082$, $t(46) = -2.98$, $p = .0046$. Other comparison between results for the VMS block, the Navigation block, and the Combination block did not show a significant difference; see Table 3.

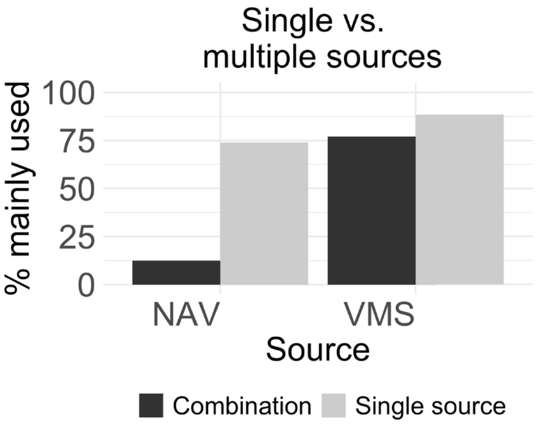

Fig. 5. Sources mainly used to support route choice decisions in single source trials and combination trials.

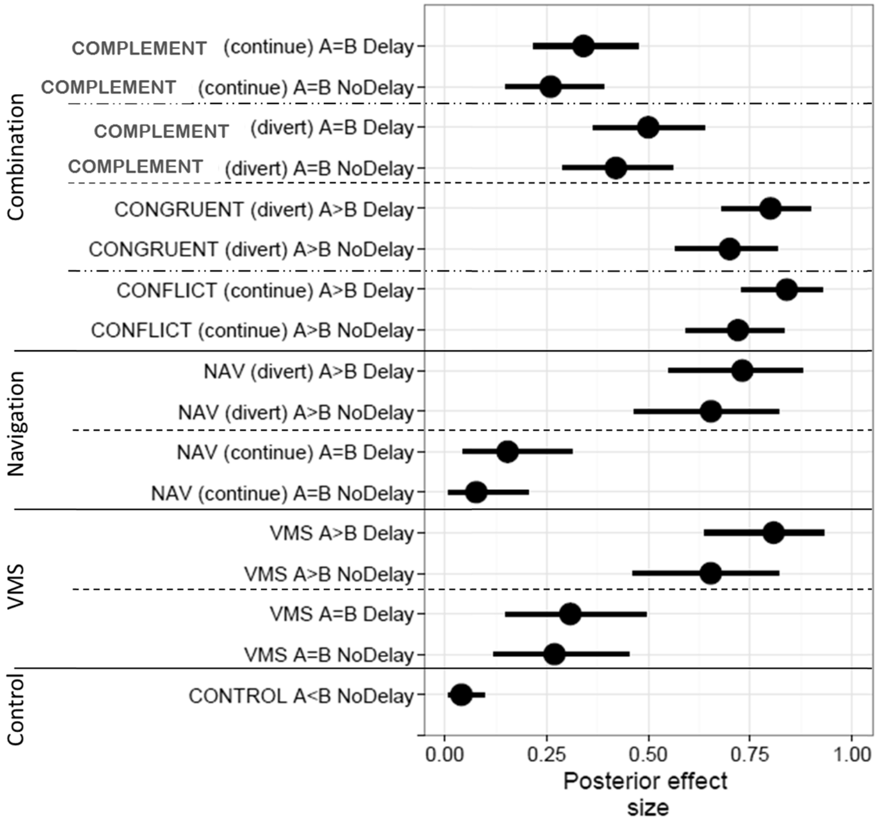

Fig. 6. Mean switching propensities and 95% credibility intervals for the four blocks.

Table 2
Results of the multilevel model including the experimental dependent variables ETT, Delay and Block.

	B	*SE B*	95% CI
Constant	0.417 ***	0.028	[0.363, 0.472]
Block (Navigation vs. Combination)	−0.082**	0.027	[-0.137, −0.027]
Block (VMS vs. Combination)	−0.043	0.027	[-0.098, 0.012]
ETT (A > B vs. A = B)	0.214 ***	0.022	[0.170, 0.259]
Delay (No delay vs. Delay)	0.044**	0.016	[0.012, 0.075]

Note. **p* < .05, ***p* < .01, ****p* < .001.

Table 3
Post hoc test Block.

	Mean difference	SE	z	$p_{bonferroni}$
Navigation - Combination	−0.082	0.027	−3.007	0.007**
VMS - Combination	−0.043	0.027	−1.574	0.26
VMS - Navigation	0.039	0.027	1.433	0.32

Note. *p* Bonferroni adjusted, **p* < .05, ***p* < .01, ****p* < .001.

4.1.4. Overview of results of the effects of multiple sources of traffic information on switching propensity

In summary, we found that compliance with the advice of the preferred source of traffic information was high regardless of the number of information sources available. However, trust in the information was significantly higher when information came from multiple sources instead of from one source. Furthermore, while there was no significant difference between trust in the traffic information from the VMS or the navigation device, participants preferred to use the information from the VMS when receiving information from both sources. Lastly, participants had a significantly lower propensity to switch when they only received information from the navigation device compared to receiving information from both the navigation device and the VMS. This difference was not found for the VMS. Thus adding descriptive information from the VMS to the prescriptive advice from the navigation device increased the propensity to switch but not visa versa.

4.2. Effects of conflicting, congruent, and complementary traffic information

The above comparisons did not take the relationship between the two sources into account, when multiple sources of traffic information were available. The effects of the three types of information, i.e. congruent, conflict, and complementary, on the use of and trust in the traffic information sources, the switching propensity, and potential driver performance measures are discussed next.

4.2.1. Primary source for route choice decision

Participants reported they mainly used the VMS to support their route choice decision when information from both the navigation device and the VMS was available to them. When subdividing the Combination block into complementary, congruent, and conflict trials, it appeared that the navigation device was used significantly more in the complementary trials compared to the congruent trials and conflict trials: Complementary (A = B, divert) vs. Congruent (A > B, divert) $\chi^2(1) = 54.00$, $p < .001$ and Complementary (A = B, continue) vs. Conflict (A > B, continue) $\chi^2(1) = 32.67$, $p < .001$, see Fig. 7.

4.2.2. Trust in traffic information sources

Examination of the range of levels of trust within participants for the three types of trials in the Combination block showed that the lowest and highest level of trust differed on average 1.38 ($SD_{congruent} = 1.17$), for the congruent trials, 1.54 ($SD_{conflict} = 1.32$) for the conflict trials, and 1.75 ($SD_{complementary} = 1.15$) for the complementary trials. Comparing average trust for the three information type trials showed no significant difference $\chi^2(2) = 0.02$.

4.2.3. Switching propensity

A within-subject repeated-measure ANOVA comparing switching propensities between the conflict, congruent, and complementary trials showed there is a significant difference for ETT, but not for Advice. A significant interaction between ETT and Advice was found, indicating a difference in switching propensity between the two types of Advice for the Complementary (A = B) trials, where people switched more for the divert advice (see Table 4 and Fig. 8).

4.2.4. Behavioural measures: average speed

Because we suspected that behavioural differences could be present between the conflicting and congruent information trials, analyses of the driving speeds were performed. The Task-Capability Interface model of the driving process by Fuller (2000) states that a driver's ability to manage task difficulty emerges out of the capability of the driver and the difficulty of the task. Because driving is self-paced, i.e. the driving speed is within bounds chosen by the driver, the driver can maintain task demands within the limits of their capability by adapting the driving speed. Lower mean speeds can be regarded as a coping strategy for higher cognitive demands (de Waard, 1996; Ranney, 1994; Young, Regan, & Hammer, 2007).

Results showed there is a small but significant difference between the mean speeds for the three information types of trials (see Table 5). Contrasts revealed that the mean speed in the complementary information trials was significantly lower than in the conflict trials, $t(1) = -2.51$, other contrasts and post-hoc analysis revealed no other significant differences (see Table 6 and Fig. 9).

4.2.5. Overview of results of the effects of conflicting, congruent, and complementary traffic information on switching propensity

To summarise: for the three types of trials of the Combination block, no significant differences in trust in the information were found. Notably this was also the case for the trials in which sources provided conflicting information. Furthermore, participants preferred information from the VMS, and compliance with the VMS was high in all three types of trials. In the trials in which the VMS provided indecisive information, i.e. the complementary trials, the navigation device was preferred significantly more to support route choice than in trials where the VMS provided decisive information. Also, in these complementary trials the advice to divert provided by the navigation device increased switching propensity significantly. More so, driving speed in these trials was significantly lower than in

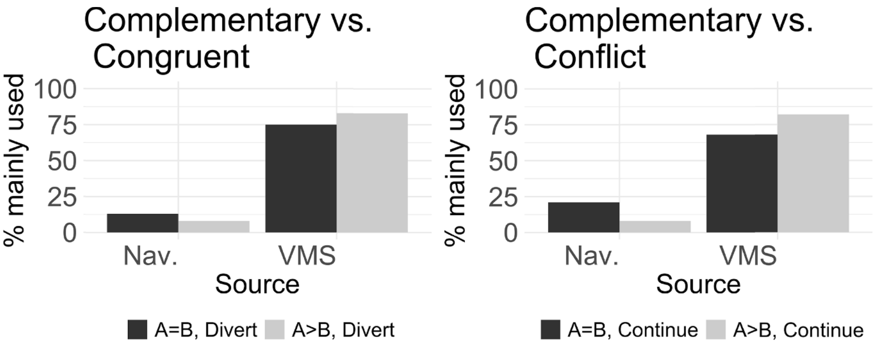

Fig. 7. Primary source to support route choice decisions for the three types of information trials in the Combination block.

Table 4
ANOVA Travel time and Advice within subject effects.

	df	Mean squares	*F*	*p*	Effect size (partial η^2)
Travel time	1	1.731	38.218	<0.001***	0.624
Residual	23	0.045			
Advice	1	0.051	1.937	0.177	0.078
Residual	23	0026			
Travel Time × Advice	1	0.107	5.647	0.026*	0.197
Residual	23	0.019			

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

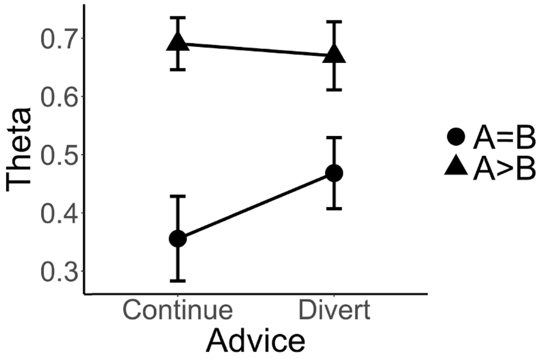

Fig. 8. Means and 95% within-subject confidence intervals (Morey, 2008) of the thetas for the two types of Advice (Continue, Divert) and the two types of ETT (A > B, A = B).

Table 5
Repeated measure ANOVA mean speed (m/s) within subject effects.

	$df^{(1)}$	Mean squares$^{(1)}$	$F^{(1)}$	$p^{(1)}$	Effect size (partial η^2) $^{(1)}$
Information type	2	0.578	3.294	0.046*	0.125
Residual	46	0.176			

Note. (1) Statistical analysis with JASP, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 6
Contrasts and post hoc *t*-test mean speed (m/s).

Test		Mean difference	SE	t	p
Contrast	Congruent - Conflict	−0.206	0.121	−1.707	0.095
Contrast	Complementary - Conflict	−0.304	0.121	−2.513	0.016*
Post-hoc	Complementary - Congruent	−0.098	0.138	−0.709	1.000$^{(\hat{})}$

Note. $\hat{}p$ Bonferroni adjusted, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

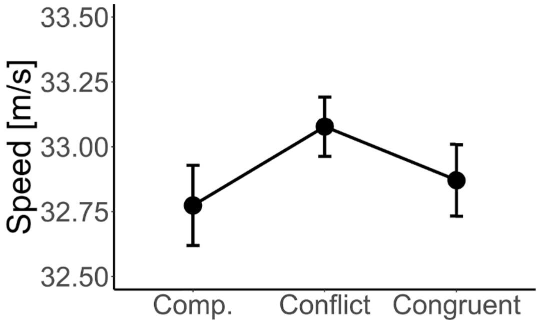

Fig. 9. Mean speed (m/s) and 95% within-subject confidence interval (Morey, 2008) for the three types of information trials in the Combination block.

the conflict trials. This could indicate increased mental workload when the complementary information needed to be processed.

5. Discussion and conclusion

The current study investigated how route choice is affected by multiple traffic information sources. We focused specifically on the interaction between prescriptive route guidance provided by a navigation device and descriptive traffic information provided by a VMS. In a driving simulator, participants drove in a virtual environment towards a motorway junction, where a route choice had to be made. Switching propensities were computed based on the route choices using a Bayesian model. In the experiment the expected travel time (ETT) for both routes, delays on one or both of the routes, and the number of available information sources were varied.

Participants had significant more trust in the information when traffic information was provided by two sources compared to one source, regardless of whether it was conflicting or congruent. This phenomenon can be explained by an "information bias", where people prefer to gather more information even when this additional information is not going to affect the action taken (Baron, Beattie, & Hershey, 1988). Furthermore, compliance with information from the preferred source, which was mostly the VMS, was high. This high compliance rate could be the result of the way the experiment was designed. Indeed, when placing participants in an unfamiliar road setting we expect compliance to be high, and because travel times were not provided after each trip, there were limited opportunities to update beliefs in the expected travel times based on actual travel information (Zhong et al., 2012). On the other hand, high compliance with the provided traffic information on VMSs is also found in other studies, for example a field study by Romero et al. (2020) and a survey study among Dutch drivers by van Beek, Dicke, Boxum, and Maréchal (2015).

As expected, participants had a significantly higher switching propensity when the travel time for the alternative route was shorter than the normal route compared to when travel times were the same for both routes. In the latter case, the propensity to switch remained quite low, as there was no travel time gain when switching routes. This inertia to switch can be explained by the concept of an indifference band, where the potential delay on the normal route does not reach the threshold to switch routes, (Srinivasan & Mahmassani, 2000). Also, the normal route is the more direct route to the destination, which also infuences route choice (Vreeswijk, Thomas, Van Berkum, & Van Arem, 2014).

The socio-demographics age, gender, and yearly mileage did not have a significant effect on route switching propensity. Previous research shows that the influence of socio-demographic variables such as, age and gender on route choice is inconclusive (Romero et al., 2020). For example, driving simulator studies by Jeihani et al. (2017) and Ardeshiri et al. (2015) do not find significant effects of age, gender, and mileage on compliance with information on a VMS. On the other hand, a driving simulator study by Yan and Wu (2014) does find an effect of age and gender on the willingness to divert, with older drivers less willing to divert and males more willing to diver than females. However, Yan and Wu (2014) do not report the age range of their participants making it is difficult to translate their findings to our results.

Against expectations, the results showed no difference in switching propensity between congruent or conflicting information. An explanation for this can be that most of our participants preferred to rely on information from the VMS. In both congruent and conflicting trials, the VMS indicated the alternative route with the shortest travel time. Thus, compliance with the VMS results in the similar and high switching propensities found for both the conflict and congruent trials.

Remarkably, a small but significant lower speed was found in the complementary information trials compared to the conflict information trials. This can indicate increased mental load in the complementary information trials. Significant differences in average speed of similar magnitude are found studying increased workload associated with the use of (handheld) mobile phones and phone conversations (see for example Haigney, Taylor, & Westerman, 2000; Patten, Kircher, Östlund, & Nilsson, 2004; Törnros & Bolling, 2006), suggesting that even these small differences in speed can be taken as an indication of increased workload. A driving simulator study by Nilsson et al. (2020) concludes that bus drivers experience an increased workload when provided with irrelevant traffic information messages. These irrelevant messages are a source for attentional dissonances and inhibiting these irrelevant messages while focusing on the driving task increases mental load (Nilsson et al., 2020). Translated to our results, it may seem counterintuitive at first that complementary information increases workload more than conflicting information. But in the conflicting information trials the preferred source of information, i.e. the VMS, provides decisive information whereas in the complementary trials this information is indecisive. This indecisive information can cause attentional dissonance, which in turn increases mental workload.

The increased use of and compliance with advice from the navigation system in the complementary information trials can also be explained by the increased mental workload in these trials. Karlsson et al. (2015) suggest that the use of a (properly) designed navigation system can help reduce workload. When the provision of indecisive information from the preferred source increases mental workload, the use of decisive information from the navigation device helps to again reduce it.

A limitation of this study is that only highly experienced car drivers participated which, relative to the general population, represents a more homogenous sample with a higher percentage of middle-aged, male participants. Although our results showed no significant effect of age, gender, and mileage, on route choice, the bias towards experienced middle-aged males in our sample may suggest a limited generalizability to the whole driver population. Yet, it should be noted that the group of middle-aged drivers is generally regarded as the driver group with the lowest crash risk (Regev, Rolison, & Moutari, 2018). Also they have the greatest situational awareness while driving (Scott-Parker, De Regt, Jones, & Caldwell, 2020) and they are most able to inhibit irrelevant messages and distractions (Karthaus, Wascher, Falkenstein, & Getzmann, 2020). The complementary traffic information already increased workload for this group of middle-aged experienced drivers in driving environment with a lower workload, i.e. with low traffic density (Teh, Jamson, Carsten, & Jamson, 2014) and no curves in the road (Jeong & Liu, 2019). It can be expected that less experienced drivers operating in demanding driving environments will experience much higher levels of workload when dealing with traffic information from multiple sources.

In the coming years it is expected that more and more traffic information will become available for car drivers. This study provides unique insights into how experienced drivers interact with multiple sources of traffic information, and how this affects their driving and route choice behaviour. Further studies with a larger and more diverse group of drivers would help us better understand these effects in the general population. Increased understanding of how drivers use multiple traffic information sources and cope with multiple sources of information can support safety and driver comfort, and help reduce the effects of information overload while driving.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

P. Imants: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **J. Theeuwes:** Writing - review & editing. **A.W. Bronkhorst:** Writing - review & editing, Supervision. **M.H. Martens:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2021.05.008.

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