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ORIGINAL ARTICLE

Framing car fuel efficiency: linearity heuristic for fuel consumption and fuel-efficiency ratings

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Abstract People are sensitive to the way information on fuel efficiency is conveyed. When the fuel efficiency of cars is framed in terms of fuel per distance (FPD; e.g. l/100 km), instead of distance per units of fuel (DPF; e.g. km/l), people have a more accurate perception of potential fuel savings. People tend to treat both DPF and FPD as linearly related to fuel consumption, while the relationship between DPF and fuel consumption is in fact curvilinear. We examined whether these incorrect assessments would also affect hypothetical car purchase choices in situations where cars also differ in relevant aspects other than fuel efficiency. Three experimental studies suggest that participants consistently employed a linearity heuristic, resulting in less optimal car choices in a DPF than in a FPD frame, and that this linearity heuristic for fuel efficiency with fuel consumption persists in the face of variations of important characteristics unrelated to fuel efficiency.

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Introduction

Imagine that your household owns two cars, a minivan you mainly use for taking the kids to soccer practice and a small car for commuting. With both cars, you travel the same distance per year. You decide to reduce the fuel consumption of your household. Would you replace your minivan that drives 7 kilometres per litre (km/l) for a newer one that drives 10 km/l, or would you replace your small car that drives 15 km/l for a newer one that drives 25 km/l? Our guess is most readers would choose to replace the small car, since this intuitively seems to result in the largest improvement in fuel efficiency.[1] However, by replacing the minivan instead, you could be saving 37.5 % more fuel.

People who wish to reduce their fuel consumption are relatively prone to switch to more fuel-efficient cars, because this allows them to significantly reduce their carbon emissions and fuel costs without having to give up their freedom to move (Poortinga et al. 2003; Steg 2003; Mogridge 1978). However, as illustrated in the dilemma above, the desire to reduce fuel consumption may not necessarily result in optimal

[1]We make a distinction throughout the paper between fuel consumption (the amount of fuel that is being used) and fuel efficiency (how efficiently a vehicle consumes fuel).

decisions in achieving this. Consumers may rely on heuristics, rather than careful elaboration, to determine the amount of fuel that can be saved by switching to a more energy-efficient car, resulting in suboptimal purchase decisions.

Larrick and Soll (2008) demonstrated that people's understanding of fuel efficiency strongly depends on how information on fuel efficiency is conveyed. There are essentially two ways to communicate or *frame* the fuel efficiency of cars: the distance that can be driven per unit of fuel (distance per unit of fuel [DPF]; e.g. km/l or miles per gallon) or the units of fuel required to drive a given distance (fuel per unit of distance [FPD]; e.g. litre per 100 km [l/100 km] or gallons per 100 miles). Framing implies that essentially the same information is presented in different ways, which has proven to have a strong influence on how people use and act upon this information (see also Tversky and Kahneman 1981). As illustrated in the example above, people can have misperceptions in understanding the relationship between fuel efficiency and fuel consumption when fuel efficiency is framed as DPF. A study in the USA showed that people may systematically misjudge the amount of fuel that can be saved by buying a more fuel-efficient car when fuel efficiency was presented as DPF, presumably because consumers incorrectly treated the relation between fuel efficiency in DPF and fuel consumption as linear Larrick and Soll (2008).

The *illusion of linearity*—the error of treating any numerical relation as though it was linear—has been identified among secondary school children (De Bock et al. 2002) and has been shown to occur to a lesser extent in young adults (Vlahović-Štetić et al. 2010). Linearity may be used as a "heuristic": a mental shortcut to solving complex problems. Heuristics may be adaptive, as they often result in a correct answer (Kahneman 2011). Indeed, applying a *linearity heuristic* in a FPD frame would result in a correct assessment of the relation between fuel efficiency and fuel consumption, as FPD is linearly related to fuel consumption. However, when the heuristic is applied in a DPF frame, it will often lead to important misjudgements about fuel consumption and fuel savings, as the relation between DPF and fuel consumption is in fact curvilinear (see Fig. 1). The curvilinear relation entails that an absolute improvement in DPF does not always result in the same amount of fuel saved. As illustrated in Fig. 1, replacing a sport utility vehicle (SUV) that drives 6 km/l by one that drives 8 km/l would reduce fuel consumption by 417 l/10.000 km. To get the same reduction in fuel consumption in the case of a more fuel-efficient car, a car that drives 15 km/l would have to be replaced by a car that drives 40 km/l. However,

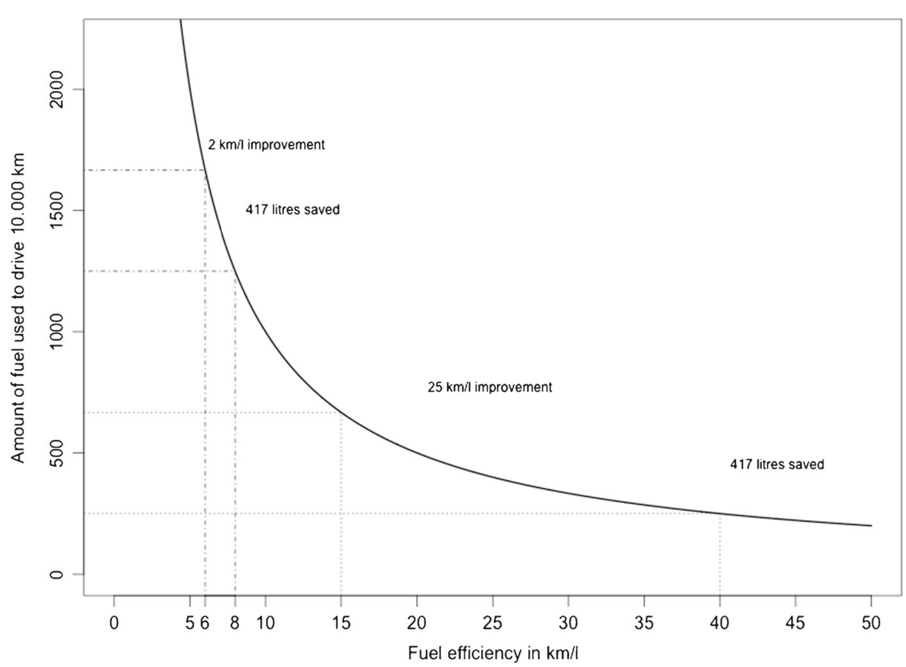

Fig. 1 Illustration of the curvilinear relation between fuel efficiency and fuel consumption for a DPF frame

when applying a linearity heuristic for assessing fuel savings in a DPF frame, people mistakenly presume that the improvement from 6 to 8 km/l is less substantial than an improvement from 15 to 40 km/l. Consequently, in a DPF frame, people underestimate the fuel savings when a relatively fuel-inefficient car is replaced by a more fuel-efficient version, while they overestimate the fuel savings by replacing an already fuel-efficient car for an even more fuel-efficient version. This finding is highly important because in many countries, including the USA and UK, fuel efficiency is usually framed in terms of DPF. In the Netherlands, where this study was conducted, both frames are used; FPD is usually used in professional communications like car advertisement, while DPF is usually used in informal and everyday conversation. This situation in the Netherlands makes it a very suitable country to investigate differences in fuel efficiency frames in a population that is likely to have encountered both types of frame.

Larrick and Soll (2008) suggested that a FPD frame provides people with a more accurate insight into fuel savings than does a DPF frame, as it becomes clear when our previous example is framed as FPD: replacing an SUV that uses 16.7 l/100 km by one that uses 12.5 l/100 km results in the same fuel reduction as replacing a smaller car that uses 6.7 l/100km by one that uses 2.5 l/100km. In this case, reasoning linearly about the relation between FPD and fuel savings correctly results in the conclusion that in both cases, 4.2 l/100 km will be saved when adopting the more fuel-efficient car. Based on this, Larrick and Soll (2008) speculated that displaying fuel efficiency as FPD rather than DPF should result in a better understanding about the amount of fuel saved when adopting a more fuel-efficient car model.

These findings could have potentially substantial implications, suggesting, for instance, that professional communication on fuel efficiency should consistently be presented as FPD, rather than DPF, as this would help people to make more optimal car purchase decisions when attempting to reduce their fuel consumption. However, to further substantiate such recommendations, additional research is needed. To what extent are more accurate perceptions on fuel savings relevant for real-life car purchase decisions? Does the linearity heuristic for fuel efficiency still play a decisive role in the more realistic situation where cars also differ on other characteristics beside fuel efficiency? And does increased understanding that might result from a FPD frame actually result in more optimal choices?

Current research

We conducted a series of studies to explore the robustness and practical implications of the use of the linearity heuristic when assessing fuel efficiency. Specifically, we examined whether incorrect assessments of fuel consumption persist when other relevant car characteristics are manipulated. In study 1, we aimed to replicate and extend the study by Larrick and Soll (2008) in a student sample. Whereas Larrick and Soll (2008) only examined the use of a linearity heuristic for the relation between fuel consumption and DPF, we additionally studied the perceived relation between fuel consumption and FPD. We expected that people would actually use a linearity heuristic in both cases, resulting in more accurate estimations of changes in fuel consumption in a FPD frame than in a DPF frame (hypothesis 1).

Besides fuel efficiency, car purchase decisions are based on many factors, including exterior, convenience, performance, economy, and safety (Byun 2001). We do not aim to identify all of these factors and their significance for the car purchase decisions. Instead, our primary interest is in testing whether the effect of fuel efficiency framing persists when participants are taking factors relevant for car purchase decisions into account. In two additional studies, we examined whether the linearity heuristic and (mis)perceptions of fuel efficiency also affect car preferences when the more fuel-efficient car is less attractive (study 2) or comfortable (study 3) than a previously owned version. Testing the robustness of the linearity heuristic, we expect that despite of differences in attractiveness or comfort of the relevant cars, the fuel efficiency frame will have an independent effect on car choice (hypothesis 2). In study 2, we tested this hypothesis in a student sample, while in study 3, we used a representative adult sample of mostly car owners. Additionally, in study 3, we examined to what extent differences in car choices indeed result from increased understanding of fuel savings. If a FPD frame indeed increases people's understanding of fuel savings, estimated fuel savings should mediate the relationship between fuel efficiency frame and car choice (hypothesis 3).

Table 1 Car pairs presented to participants in task 1 for FPD and DPF frames, and their actual fuel savings ranks (which are equal to the ranks of the improvements in the FPD frame) and ranks of the improvement in DPF

Car pairs in FPD (l/100km)	Car pairs in DPF (km/l)	Actual fuel savings rank	DPF improvement rank
A 5.00 to 4.35	20 to 23	5	3
B 14.29 to 11.11	7 to 9	1	4
C 7.14 to 4.76	14 to 21	2	2
D 5.56 to 3.85	18 to 26	3	1
E 9.09 to 8.33	11 to 12	4	5

Study 1

Study 1 aimed to replicate and extend the study of Larrick and Soll (2008). We expected to find that estimated fuel savings are consistent with a linearity heuristic, resulting in an overestimation of fuel savings from replacing relatively fuel-efficient cars, while underestimating fuel savings from replacing relatively inefficient cars in a DPF frame. Additionally, whereas Larrick and Soll (2008) reported that a misperception occurred in a DPF frame, we additionally examined whether judgements are consistent with a linearity heuristic in both FPD and DPF frames. Also, as we conducted the study in the Netherlands, we used the metric system to frame our units (using kilometres instead of miles and litres instead of gallons). This has the additional advantage that we can study whether or not the misperceptions are limited to specific units or occur in any DPF frame. Additionally, as both DPF and FPD frames are regularly used in the Netherlands, we were able to test the linearity heuristic for fuel efficiency and fuel consumption in a sample that is familiar to both frames. Finally, we allowed and encouraged participants to use a calculator to rule out calculation error as a possible explanation for any differences between DPF and FPD frames.

Method

First year psychology students ($N = 93$) participated in an online questionnaire study for course credits. We manipulated fuel efficiency framing as DPF or FPD as a between-subject variable. We tested hypothesis 1 in two different tasks that were based on the work of Larrick and Soll (2008).[2] The first task consisted of a sorting task where respondents were presented with a list of five pairs of cars. The fuel efficiency rating of each car was presented as either DPF or FPD depending on the subject's experimental condition. Each pair consisted of one previous, fuel-inefficient car, as well as one new, more fuel-efficient car. Respondents were asked to rank the five pairs of cars based on how much fuel could be saved by replacing the previous car by the new car (see Table 1 for an overview of the used car pairs).

We correlated the ranks that participants provided with the correct ranks (those based on our calculation of the actual fuel savings per pair), as well as with the ranks based on linear improvement in DPF and ranks based on the proportional improvement in DPF. These correlations allowed us to classify the tactics that participants used to estimate fuel savings, namely whether the participants' answers were consistent with a relation between fuel savings and fuel efficiency that was either curvilinear, linear, or proportional. We expected that participants, in both frames, would rely on a linearity heuristic, resulting in more accurate ranking of the pairs based on fuel savings in the FPD frame than in a DPF frame. Additionally, we expected that participants would use a linearity heuristic, translating in a tendency for participants to base their ranking on the magnitude of the linear improvement in DPF.

[2] We decided not to include the second task designed by Larrick and Soll (2008) that measured willingness to pay for different more fuel-efficient car versions of a base model, because we considered willingness to pay as an indirect measure of the relation between fuel efficiency and fuel consumption.

In the second task, we asked participants to imagine a company having two types of cars in use: a smaller fuel-efficient model and a larger fuel-inefficient model. We indicated that the company has 100 cars of each type and that all cars drive the same distance every year. The company could replace either all small or all large cars for a more efficient version of that car, and participants were asked which cars they would choose to replace in order to maximise fuel savings. Fuel efficiency ratings were either framed as FPD or DPF in a between-subject design, where the actual fuel efficiency and fuel savings were the same for both frames. Replacing the inefficient cars resulted in a larger overall decrease in fuel consumption and FPD (from 16.67 to 12.5 l/100 km) than replacing the efficient cars (from 8.33 to 5.00 l/100 km). However, the increase in DPF for the efficient cars (from 12 to 20 km/l) was larger than that for the inefficient cars (from 6 to 8 km/l). As we expected participants to use a linearity heuristic in both frames, we expected that the inefficient vehicle would be replaced more often in a FPD frame than in a DPF frame.

Results and discussion

In terms of total fuel savings achieved, the correct order of pairs was B, C, D, E, A. In line with hypothesis 1, we found that significantly more participants in the FPD frame (40.8 %) ranked the car pairs in the correct order than those in the DPF frame (15.9 %) ($t(91) = 2.717, p = 0.008$). Furthermore, when examining the tactics used to rank the pairs in the DPF frame further by correlating the rankings that participants used with (1) the correct ranking, (2) a linear ranking that sorted the pairs on absolute linear increment of DPF, and (3) a proportional ranking that sorted the pairs based on the percentage of increment in DPF, we found that rankings of 47.7 % of the participants correlated most strongly with the incorrect linear tactic, 25.0 % of the rankings correlated strongest with a proportional tactic, and 11.4 % of the rankings did not clearly correlate with any of the tactics. Only 15.9 % correlated most strongly with the correct rankings. These results suggest that the rankings assigned by the majority of participants was consistent with a linearity heuristic, and that most respondents did not accurately consider the actual nonlinear relationship between fuel efficiency and fuel savings. Because the relation between FPD and fuel consumption is linear, and the relation between DPF and fuel consumption is curvilinear, the use of a linearity heuristic would result in a more accurate assessment of fuel savings in a FPD frame than that in a DPF frame.

In our second task—where participants were asked to replace either 100 fuel-inefficient or 100 fuel-efficient cars—we found that significantly more people chose to replace the car that resulted in the highest fuel savings in the FPD frame than that in the DPF frame (73.5 versus 31.8 %) ($t(88.637) = 4.365$, $p < 0.001$).

Overall, these results reveal that many people make fuel efficiency rating judgements that are consistent with a linearity heuristic: participants are indeed likely to relate fuel consumption linearly to fuel efficiency in both frames, while this relationship is only true for a FPD frame. The linearity heuristic leads to inaccurate assessment of fuel savings in a DPF frame, suggesting that, all other things being equal, more accurate knowledge about fuel savings in the FPD frame translates into more optimal choices than in a DPF frame. However, in real-life car purchase situations, all other things are hardly ever equal. Would this linearity heuristic still affect car choice when cars differ in other important aspects, such as comfort or attractiveness?

Study 2

In the first study, we found that inaccurate assessment of total fuel savings particularly occurred in a DPF frame. In this study, we explored whether the use of a FPD frame affects the preferences for purchasing a new car, even when the relevant cars differ on other aspects besides fuel efficiency. We designed an experiment to test whether people still make more optimal choices in a FPD frame than in a DPF frame when the cars vary in attractiveness as well.

Method

Second year psychology students ($N = 189$) filled in a questionnaire that was part of their course material. Participants were asked to imagine running a household with a large and a small car of which either one could be replaced by a hybrid (more fuel-efficient) version in the same category. We indicated that both cars drove an equal distance per year and would keep doing so in the future, and that the large car used more fuel than the small car. Participants were asked which of the two cars they would replace for a hybrid version. We manipulated fuel efficiency framing as either DPF or FPD as a between-subject variable. In the FPD condition, participants learned that replacing the large car would improve the fuel efficiency from 11.11 to 9.09 l/100 km, while replacing the small car would improve the fuel efficiency from 5.56 to 4.35 l/100 km (note that replacing the large car saves 2.02 l/100 km, while replacing the small car saves 1.21 l/100 km). When framing the same situation as DPF, the DPF of the large car increased from 9 to 11 km/l, while the DPF of the small car increased from 18 to 23 km/l (note that the increase in DPF for the large car is 2 km/l, while the increase in DPF for the small car is 5 km/l). So, replacing the large car would result in the largest overall decrease in fuel consumption for the household.

Additionally, we systematically manipulated the attractiveness of the hybrid cars as a between-subject variable. We either indicated that the hybrid small car was less attractive than the previous small car, or that that the hybrid large car was less attractive than the previous large car. In the control condition, we indicated that both hybrid cars were equally attractive as their previous equivalents. We expected a main effect of fuel efficiency frame (i.e. we expected respondents in the FPD condition to more often replace the larger car) as well as a main effect of attractiveness (i.e. we expected respondents to less often choose the option where the hybrid car was less attractive than the previous car). Testing the robustness of the linearity heuristic, we anticipated no interaction effect because we expected the fuel framing effect to arise independent of competing factors, such as the attractiveness of the car.

Results and discussion

An analysis of variance was performed with a choice of car to replace as the dependent variable and with attractiveness and fuel efficiency frame as the independent variables. As expected, we found a main effect of attractiveness of the car ($F(2, 169) = 14.550$, $p < 0.001$), demonstrating that, regardless of how fuel efficiency was conveyed, people were less likely to choose the hybrid car when it was positioned as less attractive than its previous equivalent. A repeated contrast analysis revealed no significant differences in the proportion of respondents that exchanged the small car between the condition where the hybrid small car was less attractive than the previous car and the control condition (22.4 versus 22.8 %) ($t(169) = 0.559$, $p =$ ns). However, compared to the control condition, respondents replaced the large car less often when the hybrid large car was less attractive than the previous large car (41.7 versus 77.2 %) ($t(169) = 4.316$, $p < 0.001$). These results show that participants had taken the competing factor into account when making a decision for which car to replace (see Fig. 2 for a summary of these results).

Furthermore, in support of hypothesis 1, we found a main effect of fuel efficiency frame ($F(1, 169) = 26.735$, $p < 0.001$) (see Fig. 2). In the FPD frame, significantly more people chose to replace their inefficient (large) car for a hybrid version than in the DPF frame (80.44 versus 48.19 %). This means that a FPD frame resulted in a greater tendency to replace inefficient cars, on top of other considerations that may effect car purchase, in this case whether a car is less attractive than the present car. No interaction effect was found, suggesting that the fuel efficiency frame and our manipulation of attractiveness had an independent influence on the car choice decision.

These results confirm our hypotheses and suggest that framing fuel efficiency as FPD can improve decision making even when competing factors play a role. Overall, 80.4 % of the participants in the FPD frame chose to replace the large car versus 48.2 % in the DPF frame. In the version where the new large car was less attractive than the current large car, still 53.1 % of the participants in the FPD frame replaced the large car compared to only 28.6 % in the DPF frame. When the small car was unattractive, 100 % of the participants chose to replace the large car in the FPD frame, whereas only 58.1 % in the DPF frame did so (see Fig. 2).

These results imply that the fuel efficiency frame can have a significant impact on customer decisions regardless of the attractiveness of the relevant cars. These results confirm our findings of study 1 and those of Larrick and Soll (2008) that framing fuel efficiency in a DPF frame results in robust misperceptions, resulting in suboptimal fuel-efficient choices. More importantly, framing fuel efficiency in a FPD frame resulted in more optimal fuel-efficient choices even when competing motives play a role.

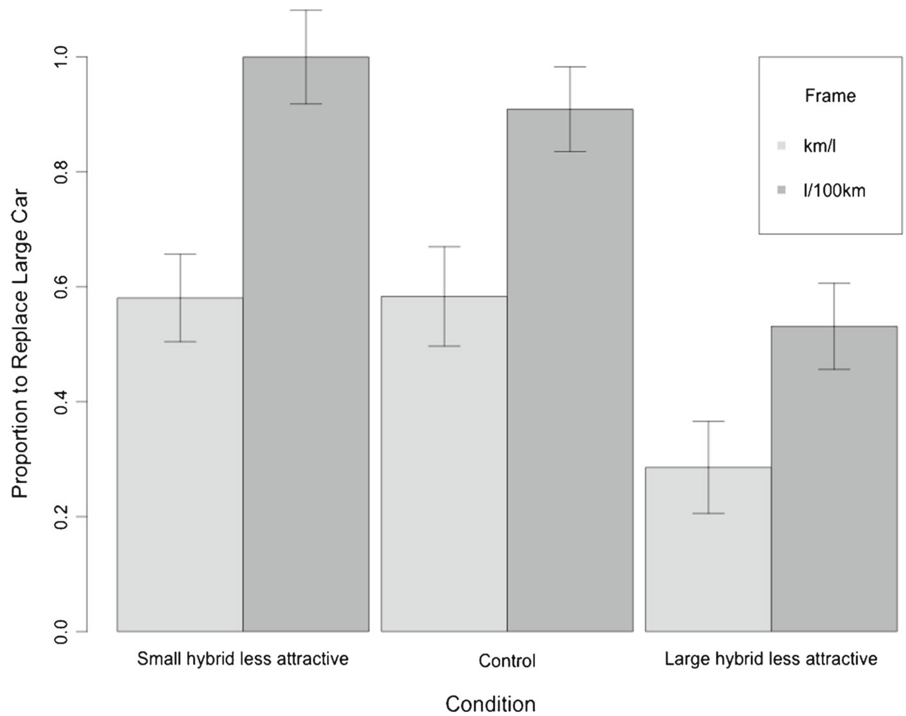

Fig. 2 Summary of results from study 2: proportion of participants per condition that chose to replace the large car for a hybrid equivalent ± SEM. Replacing the large car resulted in the largest overall fuel savings

But are these differences in fuel-efficient choices indeed due to inaccurate assessments of fuel consumption, or do people simply choose the car of which the efficiency property appears more attractive, without actually considering potential fuel savings? And can we replicate this finding in the general population, when we manipulate comfort of the car rather than attractiveness? We designed study 3 to answer these questions.

Study 3

In study 2, we found that participants made better fuel saving decisions in a FPD frame compared to a DPF frame, and that this effect persists even when manipulating attractiveness of a car. However, some questions remain to be answered. Study 3 aims to replicate the findings of study 2 with a few important changes.

First, does the linearity heuristic indeed cause misperceptions on how much fuel can be saved, and do these misperceptions affect subsequent decisions? Decisions could also simply be based on which car scores better on the fuel efficiency attribute, without actually assessing the actual amount of potential fuel savings that improvement of this property represents. We expected that the FPD frame would indeed result in a more accurate assessment of fuel savings, which in turn should result in choosing more fuel-efficient cars. Therefore, we tested whether perceived fuel savings would indeed mediate the effect of fuel efficiency frame on car choice; if true, this means that fuel efficiency frame affects the car purchase decision through its effect on perceived fuel savings.

Second, in study 2, we manipulated attractiveness of the new cars next to fuel efficiency frames and found the linearity effects to be robust, persisting when the cars also differ in attractiveness. In this study, we want to replicate the finding that the effect of fuel efficiency framing persists despite another competing factor—comfort. Therefore, we manipulated comfort of the new cars to further test the robustness of the linearity heuristic.

Third, potential car buyers are likely to have more experience in considering fuel consumption of cars than a student sample. It is conceivable that this experience reduces or eliminates the linearity heuristic when considering fuel efficiency. To test this, study 3 was conducted among a representative sample of mostly car owners in the Dutch population.

Method

We conducted an online questionnaire study among a representative sample of the Dutch adult population ($N = 349$, 50.8 % male) with a mean age of 45.3 years (SD = 13.95). Participants received a small compensation (less than one Euro) for participating in the study. We first examined whether the effect of fuel efficiency framing is indeed caused by a difference in perceived savings between DPF and FPD frames. We presented the same scenarios as those in study 2 about running a household with two cars, with the exception that comfort of the new cars was manipulated instead of attractiveness. Respondents first indicated which of the cars they would choose to replace. Next, they indicated which of the two car replacements, they thought, resulted in most fuel savings for their household on a seven-point scale, where 1 stands for the small car and 7 for the large car. We used this variable as a mediator in our analysis to test whether framing indeed affects car purchase decisions via this measure of perceived fuel consumption.

In addition, to examine the robustness of the effect of fuel efficiency framing, in study 3, we chose to manipulate comfort instead of attractiveness as a between-subject variable, next to fuel efficiency framing. Similar to study 2, in one condition, we indicated that the hybrid small car was less comfortable than the previous small car, while in the second condition, we indicated that the hybrid large car was less comfortable than the previous large car. In the control condition, we indicated that both hybrid cars were equally comfortable as their previous equivalents. As in study 2, we expected to find a main effect of fuel efficiency framing, i.e. we expected that the large car would be replaced more often in a FPD frame than in a DPF frame. We also expected to find a main effect of comfort on car choice, i.e. we expected that the less comfortable versions of the hybrid cars would be replaced less often than the equally comfortable equivalents. Again, we expected no interaction effects because we expected the main effects to be independent, indicating that the manipulation of comfort should have the same effect for both fuel efficiency frames.

Results and discussion

Similar to the results found in study 2, we performed an analysis of variance with car choice as the dependent variable and fuel efficiency frame and car comfort as the independent variables. We found a main effect of comfort on car choice ($F(2, 343) = 14.013$, $p < 0.001$). A repeated contrast revealed that

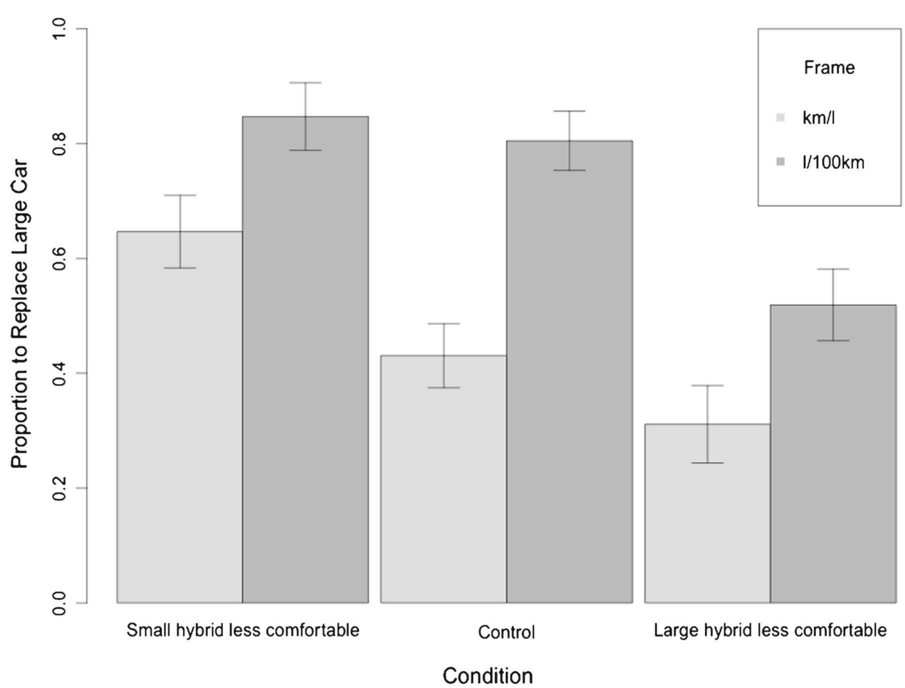

Fig. 3 Study 3: proportion of participants per condition that chose to replace the large car for a hybrid equivalent ± SEM. Replacing the large car resulted in the largest overall fuel savings

the small car was replaced less often when the hybrid small car was less comfortable than when both cars were equally comfortable (control condition; 24.5 versus 36.6 %) ($t(343) = 2.247$, $p = 0.025$). Also, when the hybrid large car was less comfortable than the previous large car, the large car was replaced less often than that in the control condition (42.3 versus 63.4 %, $t(343) = 3.400$, $p = 0.001$; see Fig. 3).

As in study 2, we found a main effect of fuel efficiency frame on car choice ($F(1, 343) = 28.269$, $p < 0.01$), providing support for hypothesis 1. The large car was replaced significantly more often in a FPD frame than in a DPF frame (73.9 versus 46.6 %). Even when the hybrid large car was less comfortable than one's current large car, more than half (51.9 %) of the participants chose to replace the large car in a FPD frame, compared to only 31 % in a DPF. In line with hypothesis 2, again no significant interaction effect was found, suggesting that the effect of fuel efficiency framing was independent of the manipulation of comfort.

To test hypothesis 3 that perceived fuel savings mediated the relationship between fuel efficiency frame and car choice, we used a macro for estimating indirect effects developed by Preacher and Hayes (2008). Bootstrap analyses showed that the total effect of fuel efficiency frame (total effect $= 1.28$, $p < 0.01$) was significantly reduced when including perceived fuel efficiency in the model (direct effect of fuel efficiency frame $= 0.60$, $p = 0.03$), suggesting that perceived fuel savings partially mediated the relation between fuel efficiency frame and car choice (with a bias corrected 95 % confidence interval for the mediation effect of 0.52 to 1.17). This finding supports our hypothesis that fuel efficiency frame indeed affects perceived fuel savings, which in turn results in a different car choice.

General discussion

In a series of experiments, we repeatedly found that participants' judgements were consistent with a linearity heuristic when assessing the relation between fuel efficiency and fuel consumption, which not only affected perceptions of fuel efficiency (cf. Larrick and Soll 2008), but also car choice decisions. In study 1, we found that, even when they were allowed to use a calculator, many participants in a DPF frame erroneously behaved consistently with a linearity heuristic for the relation between DPF and fuel consumption, which led them to make suboptimal decisions when choosing which cars to replace to maximise fuel savings. In contrast, the same linear tactic used by participants in a FPD frame resulted in more optimal assessments and decisions, resulting in greater fuel savings, suggesting a better assessment of the amount of fuel savings that could be realised by choosing a particular car. More evidence for the use of a linearity heuristic for DPF and fuel consumption was found for a sorting task and a decision-making task in study 1, replicating the findings of Larrick and Soll (2008). Additionally, we found that people generally (correctly) related FPD to fuel consumption linearly, that the linearity heuristic is also used for DPF frames other than MPG, and that the use of a calculator does not eliminate improper use of a linearity heuristic.

In the second and third studies, we found evidence that fuel efficiency frames had an effect on car choices, even when the relevant cars differed in other important aspects such as attractiveness (study 2) and comfort (study 3). This finding suggests that changing the frame of fuel efficiency in, for example, car ads, where other aspects such as attractiveness and comfort are emphasised as well, could still improve car purchase decisions.

In the third study, we found the effect of fuel efficiency framing in a representative adult sample, suggesting that experience in dealing with fuel consumption does not eliminate the linearity heuristic in estimating fuel savings. Additionally, we found that the relationship between fuel efficiency frames and car choice was indeed partially mediated by perceived fuel savings. This suggests that fuel efficiency frames indeed change how people estimate the amount of fuel that can be saved by replacing cars, which in turn affects car choices.

The three studies combined show that framing fuel efficiency as FPD indeed leads to a more accurate assessment of fuel savings and fuel consumption than a DPF frame. This finding suggest that people may be using a linearity heuristic, which would reduce misperceptions in a FPD frame compared to a DPF frame. Our results suggest that the improved decision making in a FPD frame is indeed accompanied with increased understanding of fuel savings. Also, the effect of fuel efficiency framing appears to be very robust, persisting when a calculator can be used, when competing factors have to be assessed, and even when participants have an experience with car fuel efficiency in real life, as we replicated our results in a representative adult sample. How strong the effect of fuel efficiency is in a real-world car purchase scenario, compared to other relevant factors that we have not used in our study, remains an important question.

A possible point of criticism on studies 2 and 3 is that our manipulation of attractiveness and comfort was rather abstract; we simply informed participants that they considered one of the two new cars less attractive (study 2) or comfortable (study 3) than the previous version of that car, rather than showing pictures of more or less attractive or comfortable cars or specifying attractiveness or comfort further. We decided not to use pictures and not to further specify the characteristics, as people may differ in what they find attractive or comfortable in a car. Moreover, the main effects of our manipulation show that participants did incorporate the provided information of attractiveness and comfort in their decisions, and thus show that the manipulation was successful.

Our results may have broader implications for framing and communicating energy efficiency. Although we explored the effects of framing in the context of fuel efficiency, it is likely that the effects of framing and the use of a linearity heuristic is not unique for fuel efficiency, but might be used in more situations where relationships between variables need to be assessed. A relevant example is assessing the energy efficiency of electric cars. The distance that can be travelled before recharging is often seen as an important disadvantage of electric cars (Neumann et al. 2010), therefore the range of the car on a full battery is often reported. This disadvantage was once, when fuel stations were less abundant than now, also relevant for gasoline cars, making DPF a useful frame for calculating the potential range from the amount of fuel that can be carried. However, assuming that the range on a battery charge will significantly improve in the future, we recommend to frame energy efficiency in electric cars as FPD (e.g. watt-hour/kilometre (Wh/km) or watt-hour/mile (Wh/M)), thereby focusing on energy use instead of range potential. This will make it easier to determine the amount of energy that the car uses instead of the distance that can be travelled with an amount of energy, and consequently, communicating this metric is more likely to promote more optimal energy-efficient choices of those interested in this factor. Additionally, this metric makes it easy to determine the costs of driving a certain distance with an electric vehicle, by simply multiplying the amount of energy consumed in Wh by the costs per Wh of energy.

Overall, our findings have important implications for practice. Our findings can be used to improve the provision of information on energy efficiency for users, in general, and fuel efficiency for drivers, in particular. Perceived fuel consumption and savings better reflect true fuel consumption and savings in a FPD frame. This is especially important for people who drive relatively fuel-inefficient cars, because they could perhaps be more easily convinced to replace their cars when the large potential fuel savings become more obvious in a FPD frame.

Conclusion

In sum, our general recommendation is that in order to help the public to make well-informed decisions on energy saving options, units of fuel or energy efficiency should be chosen in a way that makes it easy for consumers to assess how much energy is required to realise the intended goal. This can be achieved by using a unit of energy efficiency that is linearly related to whatever the energy is used for. In case of cars, is it interesting to know how much fuel is required to travel a certain distance, which is easier to assess in a FPD frame than in a DPF frame, because FPD is linearly related to the amount of consumed fuel.

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