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ORIGINAL ARTICLE

The primacy order effect in complex decision making

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Abstract

The goal of the present study was to assess the role of information order in situations of complex decision making in which participants have to process a large amount of information (e.g., Dijksterhuis et al. Science 311(5763): 1005–1007, 2006). In two experiments, participants were presented with information about four cars, each characterized by 12 attributes. Immediately following the presentation of the 48 sentences describing these four cars, participants had to choose the one they would prefer to purchase. Two cars shared exactly the same positive and negative attributes, but they were displayed in a different order for each car. For one car, positive attributes were systematically displayed at the beginning while it was the reverse for the other car. The two remaining cars were used as fillers and had a lower number of positive attributes than the target cars in Experiment 1 and a higher number of positive attributes in Experiment 2. Results revealed a massive effect of information order with a clear preference for the car with positive information presented at the beginning. The second experiment further showed that this order effect was maintained and still strong even if the target cars did not have more positive attributes than the filler cars. Interestingly, in both experiments, participants never noticed that two cars were exactly characterized by the same list of attributes. These data clearly demonstrate that information order is a critical factor in complex decision-making situations involving a large amount of information.

Introduction

In an influential (and controversial) study, Dijksterhuis, Bos, Nordgren and van Baaren (2006) reported experimental results supporting the idea that leaving a complex problem aside for some time is a good strategy to reach the best decision. They found that, when confronted with complex decisions, people make better choices after a period of distraction relative to a period of conscious reflection. This effect has been dubbed the "unconscious thought effect" (UTE) because unconscious processing of decision information is assumed to occur during the distraction period. According to these authors, complex decisions usually involve several alternatives and require integrating large amounts of information. Given that consciousness has a limited processing capacity, trying to think hard and to integrate this large amount of information tends to saturate working memory. In contrast, the processing capacity of the entire cognitive system (combining its conscious and unconscious parts) would have a much larger processing capacity. Unconscious thinking would, therefore, be better designed to integrate huge amounts of information and, therefore, to help us face complex decisions more efficiently.

Following up on this spectacular result and this intriguing theoretical explanation, several studies have been conducted to better understand this empirical phenomenon. Most of these studies were designed as replications or variants of the original UTE. In these situations, participants were presented with positive and negative information about a set of options (e.g., cars or apartments). After a period of conscious reflection or a period of distraction (during which they had to pay attention to a secondary task) participants finally had to decide what would be their best choice. The decision situation was considered as complex due to the large amount of information that participants had to process to generate their decision (e.g., they had to choose the best car among four, each car being characterized by a set of 12 attributes).

The main outcome of these empirical studies was that the robustness of the original result had—at least—to be questioned. Different meta-analyses or reviews have been reported and some have observed positive evidence in favor

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of the UTE (i.e., Strick, Dijksterhuis, Bos, Sjoerdsma, van Baaren, & Nordgren, 2011), but many others found little (i.e., Acker, 2008) or no evidence at all (Huizenga, Wetzels, van Ravenzwaaij, & Wagenmakers, 2012; Nieuwenstein, Wierenga, Morey, Wicherts, Blom, Wagenmakers, & van Rijn, 2015; Newell & Rakow, 2011; Newell & Shanks, 2014). Some studies also reported better choices in the distraction condition but provided alternative explanations of the results that did not require any intervention of unconscious processes (e.g., Payne, Samper, Bettman, & Luce, 2008; Rey, Goldstein, & Perruchet, 2009; Waroquier, Marchiori, Klein, & Cleeremans, 2010). Other studies have shown that crucial factors, such as the presentation format of decision information or the cognitive load of the distraction task, could account for the UTE and may therefore explain the empirical discrepancies (e.g., Waroquier, Marchiori, Klein, & Cleeremans, 2009; Abadie, Waroquier, & Terrier, 2015, 2017).

The present study was not designed to provide an additional test of the UTE but to explore the role of a critical factor that seems to influence decision makers in this type of experimental setting. This factor, that has been less studied and frequently not controlled in previous UTE studies, is the order of presentation of positive and negative information during the initial presentation phase of the experiment. As argued by Newell, Wong, Cheung, and Rakow (2009), the discrete and sequential presentation of attribute information at the beginning of the experiment invites participants to treat it as an "online judgment task" (Hastie & Park, 1986). This contrasts with "end-of-sequence judgments" (Hogarth & Einhorn, 1992) or judgement tasks from memory (Bröder & Schiffer, 2003) where the decision is done after the relevant information has been processed. In this last case, decisions are less sensitive to the order of presentation than for "online judgment task". Newell et al. (2009, Experiment 4) tested the role of information order in a typical UTE experiment and found that participants were indeed influenced by the presentation order of positive and negative information: participants chose more frequently the car for which positive attributes were presented during the last part of the presentation phase. This result suggests that, in this decision task, participants are likely engaged in an online updating of the information about the options (see also Waroquier et al., 2010; Lassiter, Lindberg, Gonzalez Vallejo, Belleza, & Phillips, 2009).

In a related study, González Vallejo, Cheng, Phillips, Chimeli, Bellezza, Harman, Lassiter and Lindberg (2014) tested participants in the same sequential data acquisition task and contrary to Newell et al. (2009) who reported a recency effect, they consistently observed a primacy effect in three successive experiments: positive information encountered earlier exerted a stronger influence on decisions than when encountered later. Although inconsistent with Newell et al. (2009) observation, the literature on impression formation has already shown that both primacy and recency effects can be obtained in this type of experimental paradigm. For instance, in a study providing a detailed analysis of order effects in belief updating, Hogarth and Einhorn (1992) clearly showed that both primacy or recency effects can be observed in this kind of situation and that they are arising from the interaction of information-processing strategies and task characteristics (see also Lange, Thomas, Buttaccio, Illingworth, & Davelaar, 2013). They notably identified key task variables that have an influence on the nature of order effects such as the complexity of the stimuli, the length of the series of evidence items, and the mode of response. By following Hogarth and Einhorn's (1992) approach and by precisely looking at the experimental differences between Newell et al. (2009) and González Vallejo et al. (2014), one can reconcile these apparent opposite results.

Indeed, while the experiments of González Vallejo et al. (2014) followed the general design used in many decision experiments of this type (i.e., 4 cars, each car being characterized by 12 attributes, car attributes being mixed up during the presentation phase), Newell et al. (2009, Exp. 4) only used two cars, each having 20 attributes (10 positive and 10 negative), and the presentation of positive or negative attributes was done in a blocked manner (i.e., participants saw a list of positive attributes for one car followed by a list of negative attributes for the other car, see their Appendix B). Therefore, the reason why Newell et al. (2009, Exp. 4) observed a recency effect is more likely due to their presentation method and notably, to the presentation of a long list of negative information about the alternative car at the end of the presentation phase suggesting that participants were more likely not to choose the alternative car due to this massive amount of recent negative information about that car.

The aim of the present study is to further explore this order effect in situations of complex decisions involving many information and to report additional empirical evidence regarding this crucial factor. Again, note that our goal is not to provide an additional test of the UTE but instead to better understand the influence of information order in complex decision paradigms. We, therefore, used the same decision paradigm as the one used in the several studies conducted after Dijksterhuis et al. (2006) but without any manipulation of the post-presentation phase of the attributes (i.e., conscious or unconscious thoughts). Participants simply had to make their decision immediately after the presentation phase.

In two experiments, participant had to choose among four hypothetical cars, described by twelve attributes (with positive or negative valences), which one seemed to be the "best". We tested the order effect using an original experimental feature that should help clarifying the interpretation of order effects. Indeed, among the four cars, there were two cars having exactly the same list of 12 positive and negative attributes, with each car having a different name (e.g., Hatsdun or Nabusi, counterbalanced across participants) and a different presentation order of their positive and negative attributes. For one car, all positive attributes were systematically presented before all negative attributes while it was the reverse for the other car. The other two cars were filler cars with a random presentation of their positive and negative attributes. Given that two cars had exactly the same attributes, we also asked participants at the end of the experiment if they became aware of that critical feature.

Experiments 1 and 2 had exactly the same structure except for the distribution of positive and negative attributes among the four cars. In Experiment 1, the two identical cars were clearly the best cars because they had 7 positive and 5 negative attributes while the filler cars had 4 positive and 8 negative attributes. The positive attributes of the two identical cars were also selected among the most important attributes for purchasing a car. In Experiment 2, the number of positive attributes was lower for the two identical cars: they had 3 positive and 9 negative attributes while the filler cars had 6 positive and 6 negative attributes. Note that the three positive attributes from the two identical cars were the three most important attributes for purchasing a car. Therefore, these experiments provide new empirical tests of the order effect that will help clarifying its nature (recency vs. primacy). The manipulation of the relative number of positive attributes between the two identical cars and the filler cars will also allow us to evaluate, in a complex decision-making situation, the magnitude of the order effect compared to the effect of the absolute number of positive attributes.

Experiment 1

Method

Participants

Twenty-eight students (17 female; mean age = 22.4 years, SD = 3.6) from Aix-Marseille University participated in this experiment. They either received course credit or monetary reward for their participation.

Material and procedure

The present experiments follow the same general structure and use the same material as Experiment 1 from Dijksterhuis et al. (2006). At the beginning of the experiment, participants were instructed that after receiving information about four hypothetical cars, they would be asked to choose the car they perceived to be the "best". Participants were then first presented with information about these four cars. Each car was characterized by the same set of 12 attributes used in Dijksterhuis et al. (2006). Among the four cars, Cars 1 and 2 had exactly the same set of attributes composed of the same seven positive and the same five negative attributes. The seven positive attributes corresponded to the seven most influent attributes in buying a car. To estimate attribute influence, we used the scale reported in Rey et al. (2009). This scale was obtained by asking a group of 18 students to rate these attributes on a 20-point scale depending on how influential they thought these attributes would be in choosing a car (0 = very low influence and 20 = very strong influence). A mean value of influence was then calculated for each attribute (see Appendix A). The two remaining cars (cars 3 and 4) had four positive and eight negative attributes, none of the positive attributes being selected among the four most influent attributes. The combination of the four cars and 12 attributes led to 48 sentences that were presented one at a time for 6 s (e.g., "Car 1 has a good mileage" or "Car 3 has no cup-holders"). Following Dijksterhuis et al. (2006), each car was given a name (Hatsdun, Nabusi, Kaiwa, Dasuka) that was different for each participant to control for name effects. Apart from the constraints on attribute order for Cars 1 and 2 (that are described in more detail in the next paragraph), the 48 sentences were presented in a different random order for each participant.

The order of presentation of the attributes was manipulated for Cars 1 and 2 such that positive attributes for Car 1 were systematically displayed at the beginning of the experiment (in a random order) and were systematically followed by negative attributes (also in a random order). The information about Car 2 was displayed in the reverse order: negative attributes systematically appeared first and were followed by positive attributes. Information about Cars 3 and 4 was displayed randomly (see Appendix B for an example of the presentation order for the resulting 48 sentences). Immediately after processing the 48 sentences, participants were asked to choose their best car. Then, they had to rate each attribute on the same 20-points scale used in Rey et al. (2009). Finally, to check if they had noticed that Cars 1 and 2 had exactly the same set of attributes, they were asked to give any comment regarding the experiment.

Results

Choices

The percentages of choices for each of the four cars are displayed in Table 1. A Chi-square test revealed a main effect of car-type [χ^2 (3, N = 28) = 43.14, $p < 0.001$] with a clear and massive advantage for Car 1 (78.6%) relative to the others [10.7, 3.6, and 7.1%, for Cars 2, 3, and 4, respectively; χ^2 (1, N = 28) = 42.86, $p < 0.001$]. There was no statistical difference between Cars 2, 3, and 4 [χ^2 (2, N = 6) = 1.83, p = 0.4].

Table 1 Percentages of choices in Experiments 1 and 2

	Car 1 (Best) (%)	Car 2 (Best) (%)	Car 3 (%)	Car 4 (%)
Experiment 1	78.6	10.7	3.6	7.1
Experiment 2	50.0	14.3	25.0	10.7

Based on the participant's reports, none of them detected that Cars 1 and 2 had exactly the same set of attributes.

Attribute ratings

A Pearson product-moment correlation coefficient was computed to assess the relationship between the pattern of attribute ratings from Rey et al. (2009) and those collected in the present experiment. A highly significant relationship was found between these ratings [$r\,(10) = 0.93$, $n = 12$, $p < 0.00$], verifying the strong reliability of these estimates. Note also that we obtained a Cronbach α of 0.98 for the present set of attribute ratings indicating that this measure is highly reproducible across participants.

Discussion

In the present experiment, we found a massive effect of attribute order on the choice for the "best" car. The car having its positive attributes displayed at the beginning of the presentation (i.e., Car 1) was largely chosen as the "best" car compared to a control car having strictly the same set of attributes but displayed in the reverse order (i.e., Car 2). This result indicates that beyond the number of positive or negative attributes, the order of information presentation plays a fundamental role in complex decision making. Moreover, participants did not report any awareness of the fact that these two cars had exactly the same set of attributes suggesting that attribute order did influence their choice without any awareness of this experimental feature in a complex decision-making situation.

The present result is generally consistent with the fine-grained analysis of Hogarth and Einhorn (1992) on order effects, and more recently with the study by González Vallejo et al. (2014) who reported similar order effects for complex and long sequences of displayed information. These results also directly echo the literature on impression formation by suggesting that the order of information presentation is a central factor that plays a major role in decision making when different products or options are submitted to someone (see also Ambady & Skowronski, 2008).

Contrary to the results reported by Newell et al. (Experiment 4, 2009), we found no evidence of a recency effect (i.e., more choices for the car having the most important and positive attributes at the end of presentation). However, as mentioned in the introduction, this is certainly due to major task differences and notably to the blocked presentation of positive or negative attributes in Newell et al.'s study. Due to this experimental feature, the last 16 presented attributes in their study were composed of 8 positive attributes from the first car followed by 8 negative attributes from the second car. Therefore, the preference for the first car (that has been interpreted as resulting from the recent presentation of positive attributes) could also be due to a repulsive effect toward the second car (generated by the long list of negative attributes at the end of the presentation phase). By taking these major task differences into account, it seems that the results reported by Newell et al. (2009) cannot be considered as inconsistent with the primacy order effects observed by González Vallejo et al. (2014) and in Experiment 1.

To further explore and understand the present phenomenon, we manipulated the number of positive and negative attributes in Experiment 2. While the target cars in Experiment 1 (i.e., Car 1) had seven positive attributes and six negative attributes, the target cars in Experiment 2 only had three positive and nine negative attributes. Similarly, while the filler cars (i.e., Cars 3 and 4) in Experiment 1 had less positive attributes than the target cars (i.e., 4 vs. 7), it was the reverse in Experiment 2 (i.e., 6 vs. 3). Therefore, if the order of information presentation is more influential than the relative distribution of positive and negative attributes, then participants should still prefer Car 1 compared to filler cars. Alternatively, if the absolute number of positive attributes is more important in this decision-making situation, then participants should preferentially select Car 3 or 4.

Experiment 2

Method

Participants

Twenty-eight students (20 female; M = 19.96 years, SD = 1.60) from Aix-Marseille University participated in this experiment. They either received course credit or monetary reward for their participation. None of the participants had taken part to Experiment 1.

Material and procedure

The stimuli and the procedure were exactly the same as in Experiment 1, except for the distribution of positive and negative attributes. Cars 1 and 2 had exactly the same set of attributes but this time, it was composed of three positive and nine negative attributes. Note that the three positive attributes corresponded to the three most influent attributes on the influence scale from Rey et al., (2009).

The two remaining cars (Cars 3 and 4) had six positive and six negative attributes, with none of the positive attributes being selected among the three most influent attributes (see Appendix C). Order of presentation was the same as in Experiment 1: positive attributes from Car 1 were systematically displayed before negative attributes and it was the reverse for Car 2. Finally, presentation order for attributes of Cars 3 and 4 was random.

Results

Choices

The percentages of choices for each of the four cars are displayed in Table 1. A Chi-square test revealed a main effect of car-type [χ^2 (3, $N=28$) = 10.57, $p=0.014$], indicating that Car 1 had been selected more frequently (i.e., 50%) than the other ones [14.3, 25, and 10.7%, for Cars 2, 3, and 4, respectively; χ^2 (1, $N=28$) = 9.33, $p<0.01$]. There was no statistical difference between Cars 2, 3, and 4 [χ^2 (2, $N=14$) = 3.64, $p=0.16$]. Again, based on the participant's reports, none of them detected that Cars 1 and 2 had exactly the same set of attributes.

Attribute ratings

A Pearson product-moment correlation coefficient was computed to assess the relationship between the pattern of attribute ratings from Rey et al. (2009) and those collected in the present experiment. A highly significant relationship was found between these ratings [r (10) = 0.95, $n=12$, $p<0.001$], verifying again the reliability of these estimates. Note also that we obtained a Cronbach α of 0.97 for the present set of attribute ratings.

Discussion

As in the previous experiment, we observed a clear effect of attribute order on the choice for the "best" car. The car having its positive attributes displayed systematically at the beginning of the presentation phase (i.e., Car 1) was significantly chosen more frequently as the "best" car compared to a control car (i.e., Car 2) that had strictly the same set of attributes but displayed in a reversed order (i.e., positive attributes at the end). Moreover, even if Car 1 had only three positive attributes compared to the filler cars (i.e., Cars 3 and 4) that had twice more positive attributes (i.e., 6), participants selected more frequently Car 1 suggesting that information order might be more influential in decision making than the absolute number of positive and negative attributes. Finally, as in Experiment 1, none of the participants noticed that Cars 1 and 2 were characterized by exactly the same set of attributes indicating one more time that the influence of information order did operate without any awareness of this experimental manipulation.

If the absolute number of positive and negative attributes does not seem to be a critical factor in situations of complex decision making (contrary to the logic initially adopted in Dijksterhuis et al. study, 2006), information presentation order certainly has to be combined with attribute influence in order to adequately predict choices in such experimental settings. Indeed, in the present situation, although Car 1 only had three positive attributes (relative to six for filler cars), these three attributes were the most influent ones according to previous attribute ratings and the positive attributes of filler cars were not selected among these most influent attributes. Therefore, the effect of order information could certainly be reduced or canceled if attribute influence was more equilibrated between Car 1 and the filler cars. One can finally note that the score on Car 2 (14.3%) was statistically indistinguishable relative to the score on Car 3 (25%) and Car 4 (11%) [χ^2 (1, $N=14$) = 1.36, $p=0.24$] indicating that the advantage for Car 1 cannot only be attributed to the high influence score of the three positive attributes but genuinely to the presentation order of these attributes.

General discussion

The goal of the present study was to further explore the primacy order effect reported recently by González Vallejo et al. (2014) in a decision-making experiment derived from the influential study by Dijksterhuis et al. (2006). In two experiments, participants were presented with information about four cars, each characterized by 12 attributes. Two cars shared exactly the same positive and the same negative attributes, but that information was displayed in a different order for each car. For one car, positive attributes were systematically displayed first while it was the reverse for the other car. The two remaining cars were used as fillers and had a lower number of positive attributes than the target cars in Experiment 1 and a higher number of positive attributes in Experiment 2. Results revealed a strong effect of information order with a clear advantage for the car with positive information presented at the beginning. The second experiment further showed that the order effect was maintained and still strong even if the target cars did not have more positive attributes than the filler cars. Finally, in both experiments, participants never noticed that two cars were exactly characterized by the same list of attributes indicating that participants were largely unaware of this experimental manipulation.

These results complement the data reported by González Vallejo et al. (2014) indicating that in a situation involving several alternatives (i.e., 4 cars) and a large number of information characterizing each alternative (i.e., 12 attributes per car), information order plays a determinant role. More specifically, in these experimental conditions, the working memory capacity of participants is certainly saturated very rapidly by the large amount of information that is provided, suggesting that the influence of early information might be predominant by anchoring the participant's impression about each car quite early (Hogarth & Einhorn, 1992). Several studies have already reported similar primacy effect in related domains involving the serial presentation of information, such as in impression formation (Anderson, 1965; Asch, 1946; Peterson, & DuCharme, 1967) or in hypothesis generation (Lange et al., 2012; Mehlhorn, Taatgen, Lebiere, & Krems, 2011; Sprenger & Dougherty, 2012).

In the present experiments, the fact that Car 1 and 2 had exactly the same list of attributes makes the interpretation of the order effect more straightforward since everything was equal in this experimental situation except information order. Nevertheless, this effect could be triggered by the positive information of Car 1 that was presented earlier (compared to Car 2) but also by the presentation of negative information regarding Car 2 that was also presented at the beginning. Car 2 was by definition the best alternative to Car 1, the presentation of negative information regarding that alternative car has certainly helped participants eliminating Car 2 early from the competition with Car 1. The present experimental set up does not allow to test the differential role of prior presentation of positive or negative information but this is certainly an interesting perspective for future research.

Another interesting result obtained in Experiment 2 is the still massive preference for Car 1 (i.e., the car for which positive information was presented at the beginning) although this car did not have the largest number of positive attributes (i.e., 3 positive attributes and 9 negative, while Cars 3 and 4 had 6 positive and 6 negative attributes). Of course, the 3 positive attributes of Cars 1 and 2 were scored by participants as the most important ones when they think of a situation of purchasing a car. The strong preference for Car 1 could, therefore, result both from presentation order and the score of influence of its three positive attributes. Future research will certainly help disentangling this interaction between the number of positive attributes and their score of influence.

Furthermore, the fact that there were only 3 positive attributes for Car 1 may have been useful for maintaining this information in working memory (see Rey et al., 2009). Participants may indeed only retain few attributes per car and given our knowledge about working memory capacity and compressibility (e.g., Chekaf, Cowan, & Mathy, 2016; Mathy & Feldman, 2012), three might be the maximum number of information that can be retained about a car in these experimental conditions. It will be interesting in future research to manipulate systematically these parameters (i.e., the number, the influence and the presentation order of positive/negative information) to better understand the role of these factors (and their interactions) in these complex decision-making situations.

As mentioned earlier, the reason why Newell et al. (2009) did not find a primacy effect but a recency effect is likely due to major differences in the experimental set up (i.e., number of cars, total number of attributes, blocked presentation of attributes). However, apart from the qualitative explanation that we provided earlier about why they found a recency effect instead of a primacy effect, it would be useful to root these explanations within a computational or mathematical modeling approach. Indeed, it is interesting to note that most of the numerous studies that have been published after Dijksterhuis et al. (2006) did not provide any quantitative modeling account of their data, which would have certainly been useful to disentangle the apparent inconsistencies in the empirical evidence.

One exception is provided in the study by González Vallejo et al. (2014) who introduced a simple mathematical model derived from Hogarth and Einhorn (1992) to formalize the theoretical explanations that can be proposed to account for the primacy effect. The general idea of this modeling approach is to consider that during the presentation phase, participants develop an online impression (positive or negative) about each of the possible alternatives (in our case, four cars). In its most simple form, the model computes the impression about a given car at time t by combining the impression at time $t-1$ and the new incoming information provided at time t about that car:

$$I_t = I_{t-1} + X_t, \tag{1}$$

where I_t is the impression at time t for a given car, I_{t-1} is the impression for the same car at time $t-1$, and X_t is the valence of the attribute presented at time t for the same car. This simple model dynamically changes the impression of each car by accumulating the positive or negative evidence regarding each car. In the present experiments, since two cars had exactly the same sets of attributes, this simple model predicts that at the end of the presentation phase, both cars should generate the same impressions. However, this prediction is clearly inconsistent with the present data. The model, therefore, needs a revision to account for the primacy effect.

To improve this model, González Vallejo et al. (2014) introduced a free parameter b that will give a different weight to I_{t-1} (the impression at $t-1$) and X_t in computing I_t:

$$I_t = (1 - b)I_{t-1} + bX_t, \tag{2}$$

where b is a parameter ($0 \le b \le 1$) weighting the relative influence of the new incoming information regarding the previous impression. For $b = 0.5$, they both contribute equally in determining I_t. If $b > 0.5$, it indexes greater sensitivity to the new information relative to the previous impression, and

$b < 0.5$ favors the reversed pattern. After fitting the model to their data, they found that the best model was obtained for b values smaller than 0.5, suggesting that prior impressions play a major role in the time course of impression formation. The present data are consistent with these predictions.

One can note, however, that different revisions of Eq. 1 could account for the primacy effect. For example, the contribution of the new incoming information could decrease over time due to the saturation of information in working memory. Formally, this could lead to the following model:

$$I_t = I_{t-1} + b(t) \times X_t, \quad (3)$$

where $b(t)$ is a non-linear decreasing function that will differentially weight the contribution of X_t over time, with $(0 \leq b(t) \leq 1)$, $b(1) = 1$ and $b(t) < b(t-1)$.[1] This model also gives more weight to the initial information and can account for the primacy effect.

One can also note that impression formation for a given car (as defined by Eqs. 1–3) is totally independent from the impressions generated by the other cars. However, one may assume some form of lateral inhibition between the different possible choices (e.g., Usher & McClelland, 2001) and the initial accumulation of positive information for one car may have an impact on the impression for the other cars. One possible implementation of this idea could be

$$I_t = I_{t-1} - \alpha \times \sum I'_{t-1} + X_t, \quad (4)$$

where $\sum I'_{t-1}$ is the sum of the impression at time $t-1$ for all the other alternative cars and α is a free parameter $(0 \leq \alpha \leq 1)$ that will weigh the contribution of this lateral inhibition. This model can account for the primacy effect because the car receiving the most positive impression at the beginning will produce a long-lasting inhibition on the other cars that will not be compensated by the new incoming information.

This list of theoretical propositions indicates that there is room for model testing and for constructing cognitive models that should help us better describe the nature and the dynamics of the decision processes taking place in this type of experimental paradigm. However, models of impression formation are probably capturing only one aspect of the cognitive processes involved in these complex decision-making situations. It has indeed been proposed that human decision making involves two qualitatively distinct modes of processing. The first one is fast and associative, and has been attributed to an implicit mode of processing, while the second is slower, rule-based, and analytic and has been attributed to an explicit and more rational mode of processing (Epstein, 1994; Sloman, 1996; Evans, 2008; Kahneman, 2003). Although this dual-processing approach is one possible way to describe different mechanisms involved in these decision-making tasks (see Keren & Schul, 2009), it suggests that impression formation (the implicit side of this dual-processing approach) is certainly interacting with working memory processes involving the refreshing and the explicit processing of previously encountered information. As mentioned earlier, the primacy effect observed in the present set of experiments might be related to working memory capacity and, apart from impression formation, to the working memory limitation capacities that constrain our ability to maintain relevant information in a decision-making situation. Clearly, future modeling work will certainly propose ways of combining these different cognitive mechanisms that are likely contributing to decision making in situations involving a large amount of information.

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Compliance with ethical standards

Conflict of interest AR, KLG, MA, and PC declare that they have no conflict of interest.

Ethical approval All procedures performed in the present studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix A: List of the 12 attributes used in Experiment 1. The table represents the distribution of positive and negative attributes across the four different cars and mean scores of influence

[1] A simple equation for the non-linear decreasing function could be: $b(t) = a \times b(t-1)$, with $0.9 \leq a \leq 1$.

obtained by each attribute at the end of the experiment. Mean scores of influence obtained by Rey et al. (2009) are also provided

Attributes	Cars				Score (Experiment 1)	Score (Rey et al., 2009)
	Car 1 (Best)	Car 2 (Best)	Car 3	Car 4		
1. (Poor/good) mileage	+	+	–	–	18.4	18.3
2. (Poor/good) handling	+	+	–	–	15.9	16.5
3. (Poor/good) for the environment	+	+	–	–	15.4	15.6
4. (Poor/good) sound system	+	+	–	–	13.0	14.6
5. (Poor/good) service	+	+	+	+	13.0	14.3
6. (Easy/difficult) to shift gears	+	+	+	–	16.2	12.9
7. (Small/large) trunk	+	+	–	+	12.8	12.3
8. (Little/plenty of) legroom	–	–	+	+	10.0	11.8
9. (Old/new) car	–	–	+	–	14.6	10.2
10. Exist in (very few/many) colors	–	–	–	–	6.5	6.1
11. (Has/has no) sunroof	–	–	–	+	3.5	5.9
12. (Has/has no) cupholders	–	–	–	–	2.7	1.6

Appendix B: An example of the 48 sentences displayed in this order for one participant of Experiment 1. The symbols "+" and "–" indicate positive and negative values of the attributes, respectively. Positive attributes of the two best cars are written in bold and negative attribute are in italics. To increase the contrast with Cars 1 and 2, attribute descriptions for Cars 3 and 4 are in grey

+ For Car 4 service is good	– Car 4 is available in very few different colors
+ Car 3 has plenty of legroom	– Car 4 has no cup holders
+ Car 3 is new	**+ Car 2 has a good sound system**
+ Car 1 has good handling	– Car 3 has poor mileage
– *Car 2 is available in very few different colors*	– Car 3 has poor handling
+ Car 1 is good for the environment	**+ For Car 2 service is good**
– *Car 2 has no cup holders*	**+ Car 1 has a large trunk**
– With car 4 it is difficult to shift gears	+ Car 4 has a sunroof
– Car 3 has a small trunk	**+ With car 2 it is easy to change gears**
– *Car 2 has no sunroof*	– *Car 1 has poor legroom*
+ Car 1 has good mileage	– Car 3 is not very good for the environment
– Car 4 has a poor sound system	– *Car 1 is old*
– Car 3 has no sunroof	+ With car 3 it is easy to change gears
– Car 4 is not very good for the environment	– *Car 1 is available in very few different colors*
+ With car 1 it is easy to shift gears	+ Car 4 has plenty of legroom
– *Car 2 has poor legroom*	**+ Car 2 has good handling**
– Car 4 has poor handling	– Car 3 has a poor sound system
– Car 4 has poor mileage	**+ Car 2 has good mileage**
– *Car 2 is old*	– *Car 1 has no sunroof*
– Car 3 has no cup holders	– *Car 1 has no cup holders*
– Car 3 is available in very few different colors	**+ Car 2 is good for the environment**
+ Car 2 has a large trunk	– Car 4 is old
+ Car 1 has a good sound system	+ Car 4 has a large trunk
+ For Car 1 service is good	+ For Car 3 service is good

Appendix C: Distribution of positive and negative attributes across the four different cars in Experiment 2 and mean scores of influence obtained by each attribute at the end of the experiment

Attributes	Car 1 (Best)	Car 2 (Best)	Car 3	Car 4	Score (Experiment 2)	Score (Rey et al., 2009)
1. (Poor/good) mileage	+	+	−	−	17.7	18.3
2. (Poor/good) handling	+	+	−	−	15.3	16.5
3. (Poor/good) for the environment	+	+	−	−	15.6	15.6
4. (Poor/good) sound system	−	−	+	−	10.6	14.6
5. (Poor/good) service	−	−	−	+	12.4	14.3
6. (Easy/difficult) to shift gears	−	−	+	+	14.6	12.9
7. (Small/large) trunk	−	−	+	+	11.5	12.3
8. (Little/plenty of) leg-room	−	−	+	−	10.9	11.8
9. (Old/new) car	−	−	−	+	8.3	10.2
10. Exist in (very few/many) colors	−	−	+	+	6.0	6.1
11. (Has/has no) sunroof	−	−	−	+	3.3	5.9
12. (Has/has no) cup-holders	−	−	+	−	2.0	1.6

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