A comparison of cue competition in a simple and a complex design

Stefaan Vandorpe *, Jan De Houwer

Department of Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Gent, Belgium

Received 15 July 2005; received in revised form 10 October 2005; accepted 6 November 2005
Available online 10 January 2006

Abstract

Recent evidence suggests that controlled reasoning processes play an important role in cue competition in human causal learning (see De Houwer, J., Beckers, T., & Vandorpe, S. (2005). Evidence for the role of higher-order reasoning processes in cue competition and other learning phenomena. Learning & Behavior, 33(2), 239–249, for a review). Until now, this evidence comes almost exclusively from studies with simple designs that involved only a limited number of cues. Little is known about the role of controlled reasoning processes when the design is more complex. It is important to examine this issue because the complexity of the design could determine the resources that are available for reasoning and thus the role that reasoning plays in cue competition. We directly compared cue competition in a simple and a complex design. The results showed that complexity of the design affected retrospective cue competition but not forward cue competition. More fine grained analyses with respect to retrospective cue competition showed that unovershadowing but not backward blocking differed significantly between complexity conditions.

© 2005 Elsevier B.V. All rights reserved.

PsycINFO classification: 2343

Keywords: Cue competition; Human causal learning

* Corresponding author. Tel.: +32 9 2649143; fax: +32 9 2646489.
E-mail address: stefaan.vandorpe@UGent.be (S. Vandorpe).
1. Introduction

Learning causal relationships between events is an important skill in real life. It allows us to anticipate future events and to act adequately with respect to the environment. Suppose, for example, that a child does not learn that his bad behaviour is the cause of punishment. Not only will the child not be able to anticipate punishment when it behaves badly, it will also not be able to learn the appropriate behaviour. Despite the importance of adequately learning causal relationships, there is no consensus about how these relationships are learned. In recent years, a vivid debate is going on between researchers who emphasize the role of controlled reasoning processes and those who attribute causal learning to automatic associative processes. We report a study aimed at making a contribution to this debate.

Many studies about human causal learning focus on cue competition. Cue competition in human causal learning refers to the fact that a causal judgement about a potential cause X depends not only on information about the contingency between X and the outcome but also on the information about the contingency between an alternative potential cause A and the outcome. We can illustrate this on the basis of the food-allergy paradigm that is often used in studies on cue competition in causal learning (e.g., Vandorpe & De Houwer, 2005; Wasserman & Berglan, 1998). Imagine that a certain patient always becomes allergic after eating potatoes (cue A) and after eating potatoes and lettuce (cues A and X). Cue competition refers to the fact that judgments about the causal relation between lettuce and the allergic reaction depends not only on the information about what happens when the patient eats lettuce but also on the information about what happens when the patient eats potatoes.

In this study, we will focus on four types of cue competition effects. The most well known is forward blocking (e.g., Dickinson, Shanks, & Evenden, 1984). Forward blocking refers to the fact that causal ratings for cue X are lower when AX+ trials (cues A and X presented together and followed by the outcome) are preceded by A+ trials (cue A presented alone and followed by the outcome) than when no A+ trials precede the AX+ trials. Backward blocking (e.g., Shanks, 1985) refers to the same effect but the order of trials is reversed in a backward blocking design (i.e., AX+ trials precede A+ trials). A third cue competition effect is reduced overshadowing (e.g., De Houwer, Beckers, & Glauffier, 2002). It refers to the fact that causal ratings for cue Y are higher when BY+ trials are preceded by B− trials (cue B presented alone and not followed by the outcome) than when no B− trials are presented. Finally, unovershadowing or release from overshadowing (e.g., Larkin, Aitken, & Dickinson, 1998) refers to the same effect as reduced overshadowing but just as in a backward blocking design, the order of trials in an unovershadowing design is reversed (i.e., BY+ trials precede B− trials). Forward blocking and reduced overshadowing are referred to as forward cue competition effects, and backward blocking and unovershadowing as retrospective cue competition effects. The difference between the causal rating for Y and the causal rating for X is called forward and retrospective cue competition, respectively.

During the last two decades, the most prominent explanation of these cue competition effects (and human causal learning in general) was based on associative models of animal conditioning (e.g., Miller & Matzel, 1988; Rescorla & Wagner, 1972; Wagner, 1981) and revisions of these models that were created in order to explain retrospective cue competition effects like backward blocking and unovershadowing (e.g., Dickinson & Burke, 1996;
Van Hamme & Wasserman, 1994). According to an associative explanation of cue competition, the processes that underlie human causal learning are automatic and stimulus driven (i.e., determined mainly by the experienced events). Recently, however, there is increasing evidence that controlled reasoning processes play a role in cue competition in human causal learning (see De Houwer, Beckers, & Vandorpe, 2005, for a review).

One of the findings in favour of controlled reasoning processes is that reduced overshadowing is much stronger than forward blocking (Vandorpe & De Houwer, 2005). This is a result that is difficult to explain on the basis of associative models but fits well with controlled reasoning accounts (Lovibond, 2003; Waldmann & Walker, 2005). According to these accounts, the causal status of a blocked cue X is uncertain when the outcome always merely occurs on A+ and AX+ trials. The uncertainty about cue X is due to the fact that one cannot verify on AX+ trials whether cue X adds anything to the effect already caused by cue A alone. As a consequence of the uncertain causal status of the blocked cue X, only weak or no blocking effects should occur. The causal status of a reduced overshadowing cue Y, however, can be inferred with certainty on BY+ trials if one knows that B is not a cause of the outcome. As a consequence, strong reduced overshadowing effects should occur. These predictions were confirmed by the results of Vandorpe and De Houwer (2005).

It should be noted, however, that Vandorpe and De Houwer (2005) used a simple design that involved only very few cues. Other evidence in favour of controlled reasoning processes was also obtained exclusively in studies with simple designs (see De Houwer et al., 2005, for a review). Little is known about whether controlled reasoning processes also play a prominent role in complex designs or whether associative processes become more important as complexity of the design increases. Some researchers (e.g., Le Pelley, Oakeshott, & McLaren, 2005; Waldmann & Walker, 2005) have alluded to the possibility that processes underlying human causal learning may be dependent on the complexity of the design. As Sloman (1996) (also see Le Pelley et al., 2005) pointed out, participants will only engage in controlled reasoning processes if they have the motivation and opportunity to do so. When the complexity of the design increases, this could increase the demand on working memory and thus reduce the opportunity to engage in controlled reasoning. It is also possible that the impact of associative processes on behaviour only becomes apparent, once the controlled reasoning processes are eliminated. Therefore, the complexity of the design could have an important impact on the relative contribution of controlled reasoning processes and associative processes to human causal learning.

In this study, we examined whether the finding that reduced overshadowing is much stronger than forward blocking within a simple design (Vandorpe & De Houwer, 2005) also holds within a complex design. If this is the case, it would suggest that controlled reasoning processes also play a role in complex designs. It should also raise doubts about the

1 Whereas associative models consistently predict strong and robust blocking effects, they sometimes predict small reduced overshadowing effects provided that certain conditions are met (e.g., that cue B becomes a conditioned inhibitor or that its associability decreases because of the B– trials). Therefore, it is difficult to see how these models can explain the fact that reduced overshadowing can be significantly stronger than forward blocking (see Vandorpe & De Houwer, 2005, for a more detailed discussion). We acknowledge that the parameters of some associative models could be adjusted in such a way that they do produce stronger reduced overshadowing than forward blocking. However, such an adjustment is post-hoc and may be incompatible with other findings that are otherwise in line with predictions of the models.
argument that associative models only have problems to account for the properties of cue competition when the design is simple. If, on the other hand, associative processes become more influential as complexity of information processing increases, the difference between reduced overshadowing and forward blocking should decrease. Importantly, according to the associative models, the reduction in the difference between reduced overshadowing and forward blocking should at least be partially due to an increase in forward blocking. All associative models predict robust blocking effects. One could argue that blocking effects in simple designs are small because reasoning processes counteract the blocking effects that are due to associative processes. If this is true, then blocking should become apparent when reasoning is prevented by an increase in the complexity of the design. If, however, the observed reduction in the difference between reduced overshadowing and forward blocking is due only to a decrease in reduced overshadowing, this would support controlled reasoning accounts. Reasoning accounts predict weak forward blocking because a valid inference about cue X is never possible when the outcome always merely occurs on A+ and AX+ trials\(^2\) while it predicts reduced overshadowing to the extent that participants have the motivation and opportunity to reason. If reasoning processes are affected by complexity this should thus result in weaker reduced overshadowing but should leave blocking unaffected.

A second difference with the study of Vandorpe and De Houwer (2005) was that we examined both forward and retrospective cue competition. In forward cue competition designs, the elemental cues (e.g., A+, B−) are presented before the compound cues (e.g., AX+, BY+) while in retrospective cue competition designs, the order of presentation is reversed. From the perspective of controlled reasoning accounts, one could argue that the order of presentation in cue competition studies can have important effects. First, there are indications from the deductive reasoning literature that reasoning about information that is presented in a backward order is more difficult than reasoning about information that is presented in a forward order (Evans, Newstead, & Byrne, 1993, p. 233–234). Second, a backward order puts a higher load on working memory than a forward order. When the information is presented in a forward order (e.g., A+ followed by AX+), one has only to remember the information about the elemental trials (e.g., A+) to make an inference about the causal status of X on the subsequent compound trials (e.g., AX+). When the information is presented in a backward order, one has to remember the information about the compound trials (e.g., AX+ trials) to make an inference about the subsequent elemental trials (e.g., A+ trials). It seems plausible that more effort is needed to successfully remember what happened on a compound trial than to remember what happened on an elemental trial. If reasoning about retrospective cue competition is indeed more demanding than reasoning about forward cue competition, then the influence of complexity of the design could be more pronounced for retrospective than for forward cue competition.

The simple design (see also Table 1) of our experiment involved A+ and B− trials (the elemental stage) and AX+, BY+, and KL+ trials (the compound stage). The complex design was set up by multiplying the simple design by three. This means that each cue was instantiated three times, resulting in three different A+ trials, three different B− trials,

\(^2\) Although a valid inference is not possible, some participants nevertheless make the inference that cue X is not a cause of the outcome because cue A is the cause of the outcome (see Vandorpe, De Houwer, & Beckers, 2005). As a consequence, small blocking effects can occur.
three different AX+ trials, three different BY+ trials, and three different KL+ trials. Also, VW− filler trials were included, again instantiated one time in the simple design and three times in the complex design. This resulted in 8 different stimuli and 6 different events in the simple design, and 24 different stimuli and 18 different events in the complex design. In order to investigate the possible different influence of complexity on forward and retrospective cue competition, also the order of the stages was manipulated on a between-subjects basis. In the forward conditions, the elemental stage preceded the compound stage. In the retrospective conditions, the order of stages was reversed. The manipulation of complexity and order of learning stages resulted in four conditions: the simple forward condition, the simple retrospective condition, the complex forward condition, and the complex retrospective condition.

2. Method

2.1. Participants

A total of 75 first year psychology students at Ghent University participated for course credit. Eighteen of them participated in the simple retrospective condition, seventeen in the complex retrospective condition, and twenty each in the simple and complex forward conditions.

2.2. Design, Stimuli, and Materials

The design of the simple forward condition is given in Table 1. In the first learning stage, six A+ and six B− trials were presented. In the second learning stage, AX+ trials, BY+ trials, KL+ trials and VW− trials were presented six times each. In the complex forward condition, there were three stimuli allocated to each cue, resulting in, for example, three different A+ trials. In the simple and complex retrospective conditions, the order of the learning stages was reversed. The following eight names of foods were used for the different cues in the simple condition (translated from Dutch): mushrooms, kiwi, fish, potatoes, coffee, tomatoes, cherries and eggs. For the complex condition, the following sixteen names of foods were added to the eight names of the simple condition: apples, avocado, bananas, blueberries, broccoli, carrots, grapes, ice-cream, lemon, meat, nuts, pears, peppers, popcorn, strawberries, and toast. The cues were presented as coloured pictures of foods (15 cm high, 10 cm wide) against a white background, with the name of the food
under the picture in a black colour. The foods cherries, eggs, apples, avocado, pears and popcorn were always allocated to the filler cues V and W (cherries and eggs in the simple condition; cherries and eggs, apples and avocado, and pears and popcorn in the complex condition). Six different allocations of the other foods were used in such a way that each food was once allocated to one type of cue (i.e., A, X, B, Y, K, or L). As outcome, the message ‘allergic reaction’ in a red colour was presented under the picture and the name of the food. When the outcome did not occur on a certain trial, the message ‘no allergic reaction’ in a green colour was presented. The task was presented on a Pentium IV PC with a 17 inch screen, and implemented using a custom made Inquisit program.

2.3. Procedure

At the beginning of the experiment, the learning instructions appeared on the screen. Participants were asked to imagine that they were a medical doctor who was treating a patient suffering from allergic reactions after eating certain foods. They were told that they would see daily allergy tests on the screen one by one. Their task was to determine for each food separately to which extent it caused an allergic reaction in the patient. After reading the learning instructions, participants could press a key to start the learning stage. Each trial started with the presentation of one or two foods. After 2000 ms, information about whether an allergic reaction occurred was added at the bottom of the screen during 3000 ms. The intertrial interval (ITI) was 3000 ms. The sequence of trials was randomized within each learning stage for each participant. There was no break between the two learning stages. After presentation of all learning trials, participants were asked to judge for each food how likely it was to cause an allergic reaction on a scale from 1 to 9, where 1 stands for ‘never causes an allergic reaction’ and 9 for ‘always causes an allergic reaction’. On each test trial, the picture and corresponding name of a food was presented in the centre of the screen and participants could make their causal rating by a click with the mouse on a digit of a Likert rating scale that was presented underneath the picture and name of the food. After this click, a white screen was presented during 1000 ms. Then a new scale from 1 to 9 appeared on the screen with 1 labelled as ‘very unsure’ and 9 as ‘very sure’. On this scale, participants could indicate how confident they were about their previous causal rating. Confidence ratings were added for exploratory reasons and will not be discussed further. After entering the confidence rating, a white screen was presented for 1000 ms before the start of the next test trial. The sequence of test trials was randomized for each participant separately.

3. Results

3.1. Analysis of ratings

The results are summarized in Table 2. For the complex conditions, the mean causal rating for a cue (e.g., A) was computed as the mean of the causal ratings for the three different stimuli that were allocated to the same type of event (e.g., A+). The mean causal ratings for the elemental cues (i.e., cues that were presented on their own) are as expected. The mean causal rating of cue A, which was always followed by the outcome, was close to or equal to the highest point of the rating scale in all conditions, and the mean causal rating of cue B, which was never followed by the outcome when presented
on its own, was close to the lowest point of the rating scale in all conditions. Furthermore, also the mean causal ratings for cues V and W, which were always presented in compound but never followed by the outcome, were close to the lowest point of the rating scale.

We then conducted a repeated measures ANOVA on the causal ratings for the blocked cue X and the reduced overshadowing/unovershadowing cue Y with the causal ratings for the two cues as within-subject variable and complexity (simple versus complex) and order (forward versus retrospective) as between-subject variables. This allowed us to examine the impact of complexity and order on cue competition. The ANOVA revealed a main effect of cue, $F(1, 71) = 125.17, p < .001$, a marginally significant two-way interaction of cue and complexity, $F(1, 71) = 3.35, p < .10$, and a significant two-way interaction of cue and order, $F(1, 71) = 8.11, p < .01$. Importantly, also the three-way interaction of cue $\times$ complexity $\times$ order was significant, $F(1, 71) = 6.28, p < .05$. A closer look at the causal ratings in Table 2 indicates that this three-way interaction was due to the fact that complexity had an influence on retrospective cue competition but not on forward cue competition. This was confirmed by separate cue $\times$ complexity ANOVAs for forward and retrospective cue competition. The analysis for forward cue competition only revealed a main effect of causal ratings, $F(1, 28) = 136.60, p < .001$, but no interaction of causal ratings with complexity, $F < 1$, indicating that forward cue competition was equal in the simple and complex condition. For retrospective cue competition, the interaction of causal ratings with complexity was significant, $F(1, 33) = 6.99, p < .05$, indicating that retrospective cue competition was stronger in the simple than in the complex condition. Paired sample $t$-tests$^3$ on the causal ratings of cues X and Y revealed that cue competition was highly significant in the simple retrospective condition, $t(17) = 4.83, p < .001$, while it just failed to reach significance in the complex retrospective condition, $t(16) = 2.08, p = .054$. Finally, independent samples $t$-tests revealed that the weaker cue competition effects in the complex retrospective condition than in the simple complex retrospective condition was more due to a decrease of the causal rating of cue Y, $t(33) = 2.45, p < .05$, than to an increase of cue X, $t(33) = 1.67, p = .11$.

3.2. Analysis of blocking and reduced overshadowing/unovershadowing

Blocking was computed as the mean of the causal ratings for cues K and L minus the mean causal rating for cue X. Reduced overshadowing and unovershadowing were computed as the mean causal rating for cue Y minus the mean of the causal ratings for cue K.

---

$^3$ All $t$-tests were two-tailed.
and L. Positive scores thus indicate the presence of the respective cue competition effect. The cue competition effects blocking and reduced overshadowing/unovershadowing are given in Fig. 1.

We analysed these scores using a type of cue competition (blocking vs. reduced overshadowing or unovershadowing) × complexity (simple versus complex) × order (forward vs. backward) ANOVA, with type of cue competition as within-subject variable and complexity and order as between-subject variables. This analysis showed a main effect of type of cue competition, $F(1, 71) = 7.50, p < .01$, and a two-way interaction of type of cue competition with order, $F(1, 71) = 5.31, p < .05$. As can be seen in Table 2, reduced overshadowing was larger than forward blocking, thus replicating the findings of Vandorpe and De Houwer (2005), whereas backward blocking and reduced overshadowing differed to a lesser degree. An inspection of Table 2 suggests that the interaction appears to be primarily due to the results with the complex design rather than to those with the simple design. Although the three-way interaction of type of cue competition × complexity × order was not significant, $F(1, 71) = 2.52, p = .12$, separate analyses for forward and retrospective cue competition did confirm that complexity had an impact only in the backward condition. The analysis of forward cue competition revealed a main effect of type of cue competition, $F(1, 38) = 19.54, p < .001$, but no interaction with complexity, $F < 1$, indicating that reduced overshadowing was stronger than forward blocking in both the simple and complex condition. The analysis of retrospective cue competition did not reveal a main effect of type of cue competition, $F < 1$, but did reveal a marginally significant interaction of type of cue competition with complexity, $F(1, 33) = 3.46, p = .07$. However, paired samples $t$-test revealed that the difference between unovershadowing and backward blocking was not significant in the simple condition, $t(17) = 1.22, p = .24$, nor in the complex condition, $t(16) = 1.73, p = .11$. Finally, independent samples $t$-tests showed that unovershadowing was significantly stronger in the simple than in the complex condition, $t(33) = 2.93, p < .001$. This was not the case for backward blocking, $t < 1$.

![Fig. 1](image-url)  
**Fig. 1.** Blocking and reduced overshadowing/unovershadowing (RO/UO) as a function of complexity and order condition. White bars represent blocking effects and dark bars represent RO/UO effects. Error bars represent standard errors of the mean. Note: SF and CF stand for the simple and complex forward condition, respectively, and SR and CR for the simple and complex retrospective condition, respectively.
4. Discussion

In this study, we investigated the influence of design complexity on cue competition in human causal learning. The most important results can be summarized as follows: (1) retrospective cue competition was affected by complexity of the experimental design while forward cue competition was unaffected; (2) reduced overshadowing was significantly stronger than forward blocking and this difference was equally large when the design was complex than when it was simple; and (3) there was some indication that unovershadowing was stronger than backward blocking in the simple condition and vice versa for the complex condition, but the interaction supporting this conclusion was only marginally significant.

Our results do not only provide a new empirical contribution about the role of design complexity and order in cue competition. They also have important theoretical implications. Many aspects of the results are in line with accounts that attribute cue competition effects to controlled reasoning (e.g., Lovibond, 2003; Waldmann & Walker, 2005). First, we replicated the finding of Vandorpe and De Houwer (2005) that reduced overshadowing is significantly stronger than forward blocking. According to a reasoning account of cue competition, one can infer with certainty on BY+ trials that Y has to be the cause of the outcome, given that B is not a cause of the outcome. As a consequence, strong reduced overshadowing effects should occur. On AX+ trials, however, one can only infer with certainty that X is not a cause of the outcome if he or she can verify that X does not add anything to the effect caused by A alone. If the outcome always merely occurs on A+ trials this verification is not possible. As a consequence, participants should be unsure about the causal status of cue X and weaker blocking than reduced overshadowing should occur. Second, we demonstrated that the finding that reduced overshadowing is significantly stronger than forward blocking holds not only when the design is simple but also when the design is complex. This is an important result because one can argue that controlled reasoning plays a role only (and the difference between reduced overshadowing and blocking therefore occurs only) when the design is simple. The present results support the conclusion that forward cue competition effects are also based on controlled reasoning processes even when the design contains 24 different cues and 18 different events. This is a design of a similar complexity as the designs of studies that are typically assumed to favour associative models (e.g., Larkin et al., 1998; Melchers, Lachnit, & Shanks, 2004).

Also other aspects of the data fitted well with reasoning accounts. We observed that the impact of complexity was bigger on retrospective than on forward cue competition. This is in line with controlled reasoning accounts because one can argue that retrospective reasoning processes are more difficult than forward reasoning processes. Furthermore, more fine grained analyses of forward blocking, backward blocking, reduced overshadowing and unovershadowing showed that only unovershadowing was affected by complexity. Reasoning accounts explain this result in the following manner: Blocking will be weak when the outcome always occurs to a maximal extent on A+ and AX+ trials, both when participants engage in adequate reasoning and when they do not engage in reasoning. When they do reason in an appropriate manner, they can conclude that the causal status of the blocked cue X is unsure and only weak blocking effects should occur (see introduction). If no reasoning processes are involved and no cue competition mechanism like, for instance, the one described in the Rescorla–Wagner model exists, cue X should be treated in the same way as the overshadowing control cues and blocking should also not occur. Reduced
overshadowing and unovershadowing, on the other hand, do occur to the extent that participants have the motivation and opportunity to engage in reasoning processes. Because reasoning in a retrospective design is more demanding and thus more vulnerable to design complexity than reasoning in a forward design, one can predict that unovershadowing should be more prone to the effects of design complexity than reduced overshadowing.

Whereas the present results are in line with the predictions of controlled reasoning models, they present a more mixed picture for existing associative models. As argued by Vandorpe and De Houwer (2005; see also footnote 1 for the main tenets of the argumentation), associative models have problems explaining the fact that reduced overshadowing is stronger than forward blocking. We did not only replicate this finding of Vandorpe and De Houwer but also showed that it was not restricted to simple designs. One could argue, however, that the difference between reduced overshadowing and blocking was due not to associative learning processes but to processes responsible for the translation of associative strength into causal judgements. Most associative models are silent about the link between associative strength and causal judgement. The most common assumption is that there is an ordinal mapping between the associative strength of a cue and a causal rating. This assumption allows for a lot of flexibility. Assume, for instance, that the causal ratings for the blocked cue X, the control cue K, and the reduced overshadowing cue Y are 4.5, 5.0, 9.0, respectively. Although these data suggest that reduced overshadowing is stronger than forward blocking (as was the case in our results), it is possible that these ratings reflect associative strengths of .10 for cue X, .50 for cue K and .60 for cue Y. In this case, we have indeed stronger forward blocking than reduced overshadowing at the associative level, opposite to what the behavioural data suggest. On the other hand, suppose that the causal ratings at the end of the experiment are 1.0, 5.0, and 6.0 for cues X, K, and Y, respectively. These causal ratings suggest that forward blocking is stronger than reduced overshadowing. However, this pattern of results is consistent with associative strengths of .40 for cue X, .50 for cue K, and 1.0 for cue Y. In this case, we have stronger reduced overshadowing than forward blocking. These examples show that unless associative models become more specific about how an association translates into a causal rating, these models cannot be confirmed nor falsified with respect to predictions about the relative magnitude of differences in ratings. Hence, associative models can accommodate the fact that we found stronger reduced overshadowing than forward blocking as they can accommodate the opposite result. But if one accepts this line of argumentation, associative models should from now on only be used to make ordinal predictions about differences in ratings. This restriction would clearly limit the scope of associative models. In practice, researchers therefore typically ignore this restriction (e.g., Aitken & Dickinson, 2005; Larkin et al., 1998).

Associative models have less difficulty explaining other aspects of our data. For instance, at least some models are compatible with the fact that complexity has a bigger impact on retrospective than on forward cue competition. Original associative learning models like the well-known Rescorla–Wagner model (1972) and Wagner’s SOP model (1981) could not explain retrospective cue competition effects because these models do not allow the associative strength of absent cues to change. The Rescorla–Wagner model has been revised by Van Hamme and Wasserman (1994) and the SOP model by Dickinson and Burke (1996) in order to account for retrospective cue competition effects. Without going into detail about the specific implementations, these models have build in a within-compound association mechanism by which the associative strength of a cue that
is absent on a given trial but is associated with a cue that is present on that trial changes in the opposite direction of the associative strength of the present cue. In the case of unovershadowing, for instance, cue Y is also activated on B− trials by a within-compound association with B due to the preceding BY+ trials. As a consequence, the associative strength of cue B decreases and the associative strength of cue Y increases. Similarly, in the case of backward blocking, cue X is activated on A+ trials by a within-compound association with A due to the preceding AX+ trials. As a consequence, the associative strength of cue A increases and the associative strength of cue X decreases.

The present results concerning retrospective cue competition can be partially explained by the revised Rescorla–Wagner and completely explained by the revised SOP models if one assumes that the within-compound associations between A and X and B and Y become weaker when the design becomes more complex. If this auxiliary assumption is correct, then the associative strength of cue X should be stronger and the associative strength of cue Y weaker in the complex retrospective condition than in the simple retrospective condition. We indeed observed higher causal ratings for cue X and lower causal ratings for cue Y in the complex retrospective condition than in the simple retrospective condition. However, even if the auxiliary assumption is correct, the revised Rescorla–Wagner model does not account for the fact that unovershadowing but not backward blocking was affected by the complexity manipulation.

Finally, our results add to the existing evidence regarding the relative magnitude of backward blocking and unovershadowing. On the one hand, the results in the simple retrospective condition are more or less in line with those of Wasserman and Berglan (1998). They found, within a design almost identical to ours, that backward blocking and unovershadowing did not differ significantly, even though there was a tendency for stronger unovershadowing than backward blocking. The results that we obtained in the complex retrospective condition, however, seem to be at variance with the results of the study of Larkin et al., 1998, Experiment 1. These researchers found significantly stronger unovershadowing than backward blocking within a design that was (almost) as complex as our design in the complex retrospective condition (21 cues and 18 events). A possible difference between our study and the study of Larkin et al. that may have contributed to the discrepant results lies in the different learning procedure. Larkin et al. asked their participants to predict the outcome on every trial while our participants only had to observe the different cues and outcomes. The procedure used by Larkin et al. may have better maintained the attention of the participants to the task and may therefore have facilitated learning.

In sum, our results show for the first time that complexity of information processing affected retrospective cue competition but not forward cue competition. Although our findings can in principle be explained on the basis of associative models, we argued that the pattern of results can be explained best by assuming that the observed causal ratings were based on controlled reasoning processes that were affected by complexity in the retrospective condition but not in the forward condition. One should note, however, that we do not want to make the (non-provable) claim that forward reasoning processes will be never affected by complexity of the design. In fact, it seems reasonable to assume that reasoning can be eliminated also in a forward design when complexity is even higher than in the complex condition of the present study. If reasoning is prevented in a forward design, controlled reasoning models would predict that both blocking and reduced overshadowing should be small or absent. But regardless of what would happen if complexity is even
higher than in the present study, our study does illustrate that one cannot by definition assume that controlled reasoning processes are ruled out in human causal learning when the experimental design is complex. Rather, if one wants to conclude that the obtained results are due to automatic associative processes, he or she has to exclude the possibility that controlled reasoning processes were involved.

Acknowledgements

Stefaan Vandorpe wishes to acknowledge the Special Research Fund of Ghent University that was granted to him.

References


