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Brief Report

Blocking in children's causal learning depends on working memory and reasoning abilities

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ABSTRACT

A sample of 99 children completed a causal learning task that was an analogue of the food allergy paradigm used with adults. The cue competition effects of blocking and unovershadowing were assessed under forward and backward presentation conditions. Children also answered questions probing their ability to make the inference posited to be necessary for blocking by a reasoning account of cue competition. For the first time, children's working memory and general verbal ability were also measured alongside their causal learning. The magnitude of blocking and unovershadowing effects increased with age. However, analyses showed that the best predictor of both blocking and unovershadowing effects was children's performance on the reasoning questions. The magnitude of the blocking effect was also predicted by children's working memory abilities. These findings provide new evidence that cue competition effects such as blocking are underpinned by effortful reasoning processes.

Introduction

Causal learning has been an important focus of research for some time, but considerable debate remains over how such learning should be conceptualized. One key issue concerns whether such learning involves effortful inferential reasoning processes that place demands on working memory (De

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Houwer, 2009; Mitchell, De Houwer, & Lovibond, 2009). It is well established that the working memory resources of young children are limited (Cowan, 1997) and that these resources play an important role in cognitive development (Barrouillet & Gaillard, 2010). However, as yet no studies have examined whether working memory is linked to the development of causal learning despite this type of learning being fundamental for successfully interacting with the world. Finding a link between working memory and causal learning in children would contribute to the debate about the role of effortful processes in such learning.

In the current study, we tested children's working memory alongside what are termed *cue competition effects* in their causal learning. One key way in which models of causal learning have been assessed is in terms of their ability to account for these effects (De Houwer, Beckers, & Vandorpe, 2005; Dickinson, 2001; Shanks, 2010). Cue competition effects are demonstrations that whether or not a cue is judged as causally efficacious is, at least in part, determined by the status of other competing cues. The cue competition effect of blocking is the most widely studied phenomenon in research on human and animal causal learning. Blocking in adults has frequently been examined using the food allergy paradigm (e.g., Dickinson, 2001), in which participants' task is to judge which foods cause an allergic reaction in a patient. Participants are shown that the allergic reaction occurs when the patient eats one food type (e.g., cheese) and then are shown that the allergic reaction also occurs when the patient eats this food along with a second food type (e.g., cheese and eggs together). Blocking is demonstrated if participants then judge that the second food (eggs) is not likely to be allergy-causing. It occurs as result of participants having only been shown the second food (eggs) paired with the allergic reaction together with the competing cue (cheese), a cue that already was demonstrated to be likely to cause the reaction.

The two learning phases are labeled the *element phase,* in which participants are shown single cues paired with an outcome (denoted A+, with A representing the cue and + representing the positive outcome), and the *compound phase,* in which participants are shown two cues together also paired with an outcome (denoted AB+). Blocking is demonstrated if being shown A+ affects participants' readiness to judge B as causally efficacious. A contrasting effect is unovershadowing (Vandorpe & De Houwer, 2005); in unovershadowing tasks, presentations of the element cue in the absence of the outcome (denoted A− trials, with the minus sign meaning that no outcome occurred) increase ratings of the causal efficacy of a competing cue B if the compound cue is shown to be paired with the outcome (AB+). To use the food allergy example, if participants are shown that the allergy does not occur when cheese is eaten and then are shown that it does occur when cheese and eggs are eaten together, then participants are particularly likely to judge that eggs are allergy-causing.

A number of recent studies have examined cue competition effects in children (Beckers, Vandorpe, Debeys, & De Houwer, 2009; McCormack, Butterfill, Hoerl, & Burns, 2009; Simms, McCormack, & Beckers, 2012; Sobel, Tenenbaum, & Gopnik, 2004), and although the age at which these effects have been observed has varied between studies, it is clear that there are developmental trends that need to be explained. The current study examined the development of cue competition effects by exploring what processes were predictive of such effects in a large sample of children. The cognitive processes investigated were those implicated by the higher order reasoning account of causal learning. According to this account, cue competition effects are underpinned by controlled inferential reasoning processes (De Houwer, 2009; De Houwer et al., 2005). This view can be seen as part of a larger theoretical approach that places higher order cognitive processes at the heart of learning (Mitchell et al., 2009) and is contrasted with more traditional accounts that describe learning in associative terms (Dickinson, 2001).

If cue competition effects are a result of effortful reasoning processes, then blocking should not be observed under circumstances in which learners do not have (a) the necessary reasoning abilities and (b) sufficient working memory resources. Simms and colleagues (2012) tested the first part of this prediction in a developmental study using a novel causal learning task in which children needed to judge which foods caused a toy robot to light up and make a sound—a child-appropriate version of the food allergy paradigm used with adults. The robot was fed either single foods (the element phase) or pairs of food together (the compound phase), and levels of blocking and unovershadowing were assessed. In this task, effects were additive; that is, the outcome that resulted from two causally efficacious cues being presented together was stronger (denoted as ++) than when one causally efficacious cue appeared on its own (the weaker outcome is denoted as +). Beckers, De Houwer, Pineño, and Miller (2005) showed that when effects are not additive, blocking is weak or absent. There was a pretraining phase that demonstrated the additivity of effects to children. The weak outcome consisted of half the robot lighting up accompanied by a low quiet tone, whereas for the strong outcome the entire robot lit up along with a higher louder sound. It was argued that children would show blocking if they were able to reason as follows: "A gives an outcome +. A and B together also give an outcome +. If A and B were both causal, then the outcome would be ++. It is not; therefore, B is not causal". Children's ability to make this inference about additivity was assessed separately by showing them a single demonstration in which the robot was fed two foods, followed by a weak outcome. Children were then asked whether one or both of the foods were foods that made the robot light up. Answering this question involved reasoning that if both foods made the robot's tummy light up, then the strong outcome would have occurred, whereas in fact what had occurred was the weaker outcome.

Simms and colleagues (2012) found that performance on these questions predicted blocking on the test trials of the causal learning task itself, and blocking was not observed in any children who were unable to answer these questions perfectly. The authors concluded that making the appropriate inference about additivity is a necessary condition for blocking in this task, a conclusion that runs counter to the associative explanation of how additivity pretraining affects blocking (Haselgrove, 2010). However, there were many children who were able to answer reasoning questions but did not show blocking. Thus, being able to make the appropriate inference was on its own not sufficient for blocking. Simms and colleagues (2012) speculated that children must also possess the necessary working memory resources to combine the required pieces of information provided during the trials and then use them to make the appropriate inference.

The current study addressed this issue by measuring working memory abilities alongside children's causal learning. Children completed the robot task in either a *forward* presentation condition (element training phase first) or a *backward* presentation condition (compound training phase first). Children also completed two working memory tasks and also answered the questions used by Simms and colleagues (2012) to test the ability to reason about additivity. Our core prediction was that blocking would be related to both children's ability to reason about additivity and children's working memory abilities. We were also interested in the relationships between these measures and unovershadowing.

Method

Participants

A sample of 59 4- and 5-year-olds ($M = 59$ months, range = 48–60) and 40 6- and 7-year-olds ($M = 76$ months, range = 65–83) participated (53 boys and 46 girls). Half of the children in each age group were randomly assigned to each order condition (forward or backward). Most children were recruited and tested in their schools; however, 36 children were recruited through newspaper advertisements and were tested in our research laboratory.

Apparatus

A computer-controlled toy male robot purposely built for the causal learning task was used. Toy foods were fed to the robot by placing them in his mouth; pressing the robot's nose caused the foodstuffs to drop into his "tummy." When a foodstuff dropped into the tummy, either a weak outcome, a strong outcome, or no outcome occurred. A weak outcome consisted of only the bottom half of the tummy lighting up along with a low quiet sound. A strong outcome consisted of all of the tummy lighting up accompanied by a higher louder sound. Seven different sets of five toy foods were used, with one set being used as a training set.

Working memory was measured with a computerized adaptation of the animal recall task used by Barrouillet, Gavens, Vergauwe, Gaillard, and Camos (2009). Children were required to name the color of smiley faces that appeared on the screen in between pictures of animals and then to recall the series of animals. Four levels of increasing difficulty were created, each with four trials, with the first level

Table 1
Pretraining design (A) and element and compound training (B).

(A) Pretraining design		F+/G−/H+/I−/FG+/FH++	
(B) Element and compound training			
Presentation order	Task	Phase 1	Phase 2
Forward	Blocking	A+, E−	AB+/CD+
	Unovershadowing	A−, E+	AB+/CD+
Backward	Blocking	AB+/CD+	A+, E−
	Unovershadowing	AB+/CD+	A−, E+

Note: A minus sign (−) indicates no outcome, a plus sign (+) indicates a weak outcome, and a double plus sign (++) indicates a strong outcome. Each letter represents a different foodstuff, and different sets of foodstuffs were used for each task. C items were control cues, with responses to C compared with responses to the experimental cue B at test. E items were fillers and ensured that there were some trials in which the outcome did not occur per task. During pretraining, each trial was shown twice. During element and compound training, each trial was shown three times in a randomized order.

requiring one animal to be recalled and the fourth level requiring four animals to be recalled. A modified version of the digit recall task from the Wechsler Intelligence Scale for Children–Fourth Edition (WISC-IV; Wechsler, 2003) was also used. The British Picture Vocabulary Scale–Second Edition (BPVS-II; Dunn, Dunn, Whetton, & Burley, 1997), a test of receptive vocabulary, was administered as a measure of verbal ability.

Procedure

Children took part in two separate 25-min testing sessions that were conducted on the same day. The first session involved the first half of the robot task followed by the animal recall task. The second session involved the second half of the robot task, the digit span task, and the BPVS-II.

Robot task

Initial pretraining followed the procedure outlined in Table 1A, with each letter representing a different foodstuff. Demonstrations were given in the fixed order illustrated in the table, with each demonstration being repeated. This phase included a number of questions to ensure that children understood the nature of the task.

Learning phase. Learning trials are shown in Table 1B, with each participant completing three blocking tasks and three unovershadowing tasks. The C items act as control cues to be compared with responses to the experimental cue B at test. Because neither cue from the CD pair occurs on its own, differences between B and C at test indicate that pairing B with A had an effect on whether or not B is assumed to be causally efficacious. The presentation order of blocking and unovershadowing tasks was counterbalanced across participants. There were two learning phases in each task during which either elements (single food cues) or compounds (two foods together) were shown with their associated outcome. Each trial was shown three times, and the order of presentation of trials within each phase was varied. So, for example, in a forward blocking task, participants would see a trial involving the robot being fed one foodstuff that made part of the robot's tummy light up (A+) and would see another trial in which a different foodstuff did not make the robot's tummy light up (E−) in Phase 1. Participants saw each of these trials three times in a randomized order. In Phase 2, trials consisted of participants being presented with the compound cues along with the weak outcome (AB+ and CD+) three times in a pseudo-randomized order.

Test phase. Following learning, children were asked test questions about B and C in a counterbalanced order: "Is [food name] a food that makes the robot's tummy light up?" Children were required to give yes/no answers.[1] Children received the first three tasks in one testing session, and at the start of the

[1] Participants were also asked to make forced-choice judgments regarding B and C that are not reported here because they proved to be a less sensitive measure of performance.

second testing session they were provided with a brief reminder of the pretraining that they had experienced before completing the last three tasks.

Reasoning questions. In addition to assessing cue competition effects, children's ability to reason about additivity was also assessed. At the end of each testing session, children were initially shown a pair of foods fed simultaneously to the robot a single time, and part of the robot's tummy lit up. Children were then asked, "Does only one of these foods make the robot's tummy light up, or do both of these foods make the robot's tummy light up?"

Animal recall task

Children initially received a series of practice trials that were repeated if necessary. The practice trials were designed to ensure that children knew that they needed to name the colors of the smiley faces that appeared on the screen in between animal pictures and then recall the animals in the correct order. The first level of test trials consisted of four sets of one-animal trials, with subsequent levels involving four sets of two-animal, three-animal, and four-animal trials. If all of the animals in one of the four trials in a level were recalled, even in the incorrect order, children moved to the next level. The task was terminated when children failed to recall all of the animals in any of the four trials at a particular level. Children received a score of .25 for each animal recalled in the correct list position.

Digit recall task

A modified version of the WISC-IV digit span subtask was used. The digit sequences ranged from two to nine digits in length, with eight difficulty levels. Each level consisted of a particular digit span length being presented for two trials, with a third trial available but administered only if a single trial was recalled incorrectly. The task was terminated once children got two trials in a particular level incorrect. A score of 1 was given for each correct trial recalled in the correct order.

Results

Difference scores were calculated as follows. For blocking trials, the number of times that participants said "no" to C cues was subtracted from the number of times that participants said "no" to B

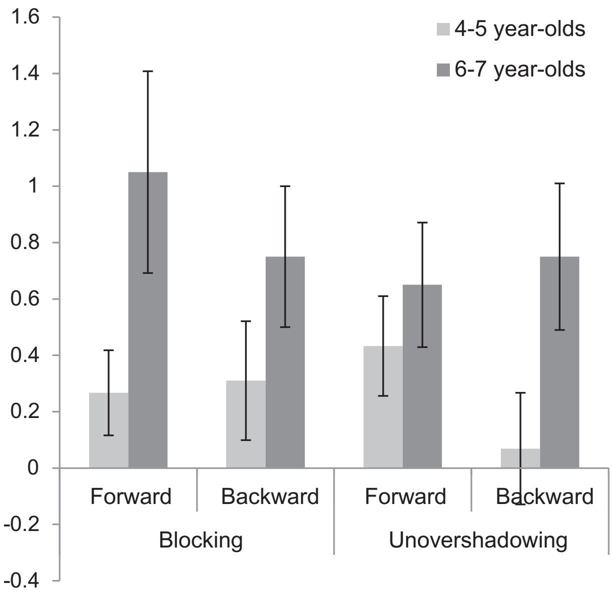

Fig. 1. Blocking and unovershadowing difference scores as a function of age and condition.

cues. For unovershadowing trials, the number of times that participants said "yes" to C cues was subtracted from the number of times that participants said "yes" to B cues. These scores provide an index of the magnitude of each cue competition effect; scores varied from −3 to +3. Fig. 1 shows scores for each presentation order and age group. It can be seen from the figure that cue competition effects are much more marked in the older group. A three-way repeated-measures analysis of variance (ANOVA) was conducted on scores with between-participants factors of order and age and a within-participants factor of type of cue competition effect (blocking or unovershadowing). There were no significant main effects of order or type of cue competition effect (both *F*s < 1), but the main effect of age group was significant, $F(1,94) = 8.50$, $p < .005$, $\eta_p^2 = .08$. There were no significant interactions. Further analyses examined whether each cue competition effect was present using one-sample *t* tests (test value = 0). Significant blocking and unovershadowing were observed in the 6- and 7-year-olds, $t(39) = 4.14$, $p < .001$, and $t(39) = 4.15$, $p < .001$, respectively. Significant blocking was also observed in the 4- and 5-year-olds, $t(58) = 2.25$, $p < .03$, but unovershadowing was only marginally significant in this age group, $t(58) = 1.90$, $p = .06$.

The age groups also differed significantly in terms of their performance on the reasoning about additivity questions, $t(97) = -3.78$, $p < .001$, with mean scores of 0.92 ($SD = 0.90$) for the 4- and 5-year-olds and 1.58 ($SD = 0.78$) for the 6- and 7-year-olds.

Correlational analysis examined the relationship between blocking and unovershadowing scores and the working memory and reasoning measures while controlling for chronological age. Blocking scores were significantly correlated with digit span ($r = .215$, $p < .05$), animal recall scores ($r = .203$, $p < .05$), and reasoning scores ($r = .397$, $p < .01$) when partialling out age. Unovershadowing scores were not significantly correlated with memory scores when controlling for age, although they were significantly related to reasoning scores ($r = .263$, $p < .01$). Regression analyses (Table 2) were used to examine the extent to which each measure uniquely predicted difference scores. Although forward digit span is not always classified as a working memory measure, we combined the scores of the digit span task and the animal recall task into a single memory measure because they were closely correlated ($r = .49$, $p < .001$). For the purposes of these analyses, *Z* scores were calculated for each participant on the digit span and animal recall tasks, and the average *Z* score was entered into the regression as a working memory measure. Working memory and reasoning about additivity were significant unique predictors of blocking scores, but that was not the case for BPVS-II scores and chronological age. For unovershadowing scores, the only significant unique predictor was reasoning about additivity.

Further analyses examined whether significant blocking was observed in subgroups of children who differed in their working memory abilities. Children were divided into two groups depending on whether they showed a positive or negative *Z* score in the composite working memory measure. One-sample *t* tests showed that significant blocking was observed only in children with positive *Z* scores, $t(46) = 5.33$, $p < .001$, whereas blocking was not significant for children with negative *Z* scores, $t(51) = 1.00$, $p = .32$. This finding suggests that good working memory is necessary for blocking in this task.

Table 2
Linear regressions on blocking and unovershadowing scores.

	Blocking			Unovershadowing		
Model	R^2	F		R^2	F	
	.292	9.707*		.131	3.542*	
Predictor	*B*	*SE B*	*t*	*B*	*SE B*	*t*
Age	.009	.014	0.644	.007	.014	0.480
BPVS-II score	−.006	.011	−0.544	.013	.011	1.115
Working memory	.380*	.165	2.306	−.023	.163	−0.140
Reasoning	.498**	.123	4.052	.299*	.121	2.458

* $p < .05$.
** $p < .01$.

Finally, we examined individual performance on the additivity questions alongside blocking scores, taking a score of at least 2 as a criterion for clearly showing blocking (see Simms et al., 2012). Among those children who did not get both additivity questions correct, only 2 of 48 clearly showed blocking, suggesting that the ability to reason about additivity is necessary for blocking in this task. However, among those children who got the additivity questions correct, although 20 clearly showed blocking, 31 did not, indicating that reasoning about additivity is not sufficient for blocking. A t test showed that those children who got additivity questions correct and also showed blocking (mean Z score = 0.53) had better memory abilities than those who got the additivity questions correct but did not show blocking (mean Z score = 0.05), $t(49) = -1.69$, $p < .05$ (one-tailed).

Discussion

This study is the first that we are aware of, in either children or adults, to examine working memory abilities alongside the cue competition effects of blocking and unovershadowing. Whether or not children showed blocking in their causal learning was related both to their working memory ability and to their ability to answer questions about additivity. Measures of these abilities were better predictors of blocking than either chronological age or children's verbal abilities, and blocking was not found in children with poorer working memory skills. Taken together, these results strongly suggest that effortful reasoning processes that draw on working memory underpin blocking in this type of task, consistent with a higher order reasoning account of causal learning. Unovershadowing scores were also predicted by the ability to reason about additivity, although not by working memory. Detailed discussion of why the ability to reason about additivity may affect unovershadowing as well as blocking is provided in Simms and colleagues (2012), who argued that this is due to such reasoning affecting responses to the control cues rather than experimental cues in the former task. Consistent with the findings of McCormack and colleagues (2009), presentation order did not have an impact on the magnitude of these cue competition effects in children (but see Simms et al., 2012).

The findings regarding a selective relationship between working memory and blocking are consistent with those of De Houwer and Beckers (2003), who found that conducting a secondary task disrupted blocking but left other aspects of causal learning intact. They also complement the extensive literature that emphasizes a key role for working memory in cognitive development (Barrouillet & Gaillard, 2010; Fry & Hale, 1996). In the context of that literature, what is distinctive about the current results is that they suggest a role for working memory even in what is usually taken to be a very fundamental type of learning.

Do we want to generalize from our findings to suggest that blocking could not be observed in very young children who lack the necessary working memory and reasoning resources? Such a generalization might already be considered as unwise given that Sobel and Kirkham (2006) argued that cue competition effects can be observed in preverbal children. Although it is not clear to us whether Sobel and Kirkham established that blocking can be observed in very young children because of the lack of appropriate control trials (see McCormack et al., 2009), we do not want to rule out this possibility. Blocking-like phenomena are widely reported in learning across the animal kingdom, and it seems likely that these phenomena could be underpinned by entirely different sets of processes depending on the learning context, species, or population being studied. Our study employed a task that was very similar to that used frequently with adult humans, over which debates are ongoing regarding the involvement of higher order processes, and our findings regarding links between blocking and reasoning/working memory have implications for how the demands of such tasks are characterized. We interpret these data as providing the best direct evidence to date for a role for memory-demanding inferential reasoning in such causal learning tasks.

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