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Schmidt, J. R., & De Houwer, J. (2019). Cue Competition and Incidental Learning: No Blocking or Overshadowing in the Colour-Word Contingency Learning Procedure Without Instructions to Learn. *Collabra: Psychology,* 5(1): 15. DOI: https://doi.org/10.1525/collabra.236

ORIGINAL RESEARCH REPORT

Cue Competition and Incidental Learning: No Blocking or Overshadowing in the Colour-Word Contingency Learning Procedure Without Instructions to Learn

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Overshadowing and blocking are two important findings that are frequently used to constrain models of associative learning. Overshadowing is the finding that learning about a cue (referred to as X) is reduced when that cue is always accompanied by a second cue (referred to as A) during the learning phase (AX). Blocking is the finding that after learning a stimulus-outcome relation for one stimulus (A), learning about a second stimulus (X) is reduced when the second stimulus is always accompanied by the first stimulus (AX). It remains unclear whether overshadowing and blocking result from explicit decision processes (e.g., "I know that A predicts the outcome, so I am not sure whether X does, too"), or whether cue competition is built directly into low-level association formation processes. In that vein, the present work examined whether overshadowing and/or blocking are present in an incidental learning procedure, where the predictive stimuli (words or shapes) are irrelevant to the cover task and merely correlated with the task-relevant stimulus dimension (colour). In two large online studies, we observed no evidence for overshadowing or blocking in this setup: (a) no evidence for an overshadowing cost was observed with compound (word-shape) cues relative to single cue learning conditions, and (b) contingency learning effects for blocked stimuli did not differ from those for blocking stimuli. However, when participants were given the explicit instructions to learn contingencies, evidence for blocking and overshadowing was observed. Together, these results suggest that contingencies of blocked/overshadowed stimuli are learned incidentally, but are suppressed by explicit decision processes due to knowledge of the contingencies for the blocking/overshadowing stimuli.

Keywords: blocking; overshadowing; cue competition; contingency learning; incidental learning; contingency awareness

Introduction

In learning psychology, two findings that have served to constrain theories of human and animal associative learning are overshadowing and blocking. *Overshadowing* is the observation that when two stimuli, termed Stimulus A and Stimulus X, are presented together and followed by an outcome (i.e., AX+ trials), evidence for learning of the X-outcome relation is weaker compared to a condition in which only Stimulus X is paired with the outcome (i.e., X+ trials; Pavlov, 1927). For instance, rats can easily learn that a light or a tone predicts a food reward, but when a light and a tone are presented together with the reward, the rat may only weakly learn the individual light-food and tone-food relations. Thus, the light and tone "overshadowed" each other (or alternatively, one cue overshadows the other, but not the reverse). *Blocking* (Kamin, 1969) is the observation that after learning that Stimulus A (e.g., light) predicts an outcome (e.g., food; A+), presentation of Stimulus A along with a new Stimulus X (e.g., tone) with the same outcome (food; i.e., AX+) weakens learning of the Stimulus X-outcome relation as compared to a condition with only AX+ trials (overshadowing). That is, even though Stimulus X and the outcome co-occurred during the compound AX learning phase, little learning of this regularity is observed. Thus, Stimulus A "blocks" learning about Stimulus X. These *cue competition effects*, overshadowing and blocking, are interesting in that they represent a challenge for simple association formation models of learning according to which co-occurrence is a sufficient condition for learning (or, put differently, the idea "what fires together, wires together"; Hebb, 1949).

Several theoretical accounts of blocking and overshadowing have been presented over the years (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Sutherland & Mackintosh, 1971). For instance, the Rescorla-Wagner

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model (Rescorla & Wagner, 1972) postulates that associative connections are only updated to the extent that an outcome was unexpected. This can account for blocking: the A-outcome association is learned early on, because the outcome is initially unexpected. When Stimulus A and Stimulus X are subsequently presented together with the same outcome (AX+), the outcome is already expected on the basis of the presence of Stimulus A. As a result, very little is learned about the Stimulus X-outcome relation. The Rescorla-Wagner model can also account for overshadowing: the first time that A and X are presented together and followed by an outcome (AX+), the outcome is unexpected. Therefore, learning (i.e., association formation) occurs for both stimuli. On subsequent AX+ trials, however, both stimuli contribute to the prediction of the outcome, resulting in less prediction error and thus less strengthening of associations compared to a condition in which only X was present on all trials (X+; i.e., prediction error is lower with two predictive stimuli, weakening further learning for both; see R. R. Miller, Barnet, & Grahame, 1995).

Importantly, cue competition effects are not observed under all conditions. For instance, overshadowing in conditioned lick suppression diminishes with extended training (S. Stout, Arcediano, Escobar, & Miller, 2003), extended cue presentation (Urushmara & Miller, 2007), short trial spacing (S. C. Stout, Chang, & Miller, 2003), and weak contingencies (Urcelay & Miller, 2006). Similarly, blocking also seems to be quite parameter dependent, as a recent 15-experiment failure to find blocking in animals illustrates (Maes et al., 2016). As will be discussed in more detail in the General Discussion, there is not always clear agreement over which factors are important in determining the coming and going of cue competition effects (cf., Maes et al., 2018; Soto, 2018), and further work is arguably still needed to more precisely clarify the moderators of cue competition effects.

One issue that still remains unclear is whether cue competition can be found in incidental learning tasks, that is, tasks in which predictive cues were not task relevant (targets). In most past reports, learning the contingency was the explicit goal and participants had ample time to reflect on the events that they saw (Chapman & Robbins, 1990; Dickinson, Shanks, & Evenden, 1984; Gluck & Bower, 1988; D. R. Shanks, 1985). For instance, in an allergy prediction task (Le Pelley & McLaren, 2001) participants are presented with symptoms (cues) and asked to predict whether the patient has a condition.

There are a few exceptions. Hendrickx and De Houwer (1997) described unpublished data with the correlational cueing paradigm (J. Miller, 1987), which is conceptually similar to the paradigm that we will adopt in the present work. In particular, participants responded to a central target letter, and flanking letters, which were predictive of the target response, served as blocking and blocked cues. Importantly, however, the task was to respond to the target. Participants were not informed about the contingencies between the flankers and the targets, nor were they required to learn those contingencies. Hence, the correlational cueing task can be described as an incidental learning task. One experiment hinted at a blocking effect, though overall response times were substantially faster in the blocking condition for unclear reasons, potentially eliminating the contingency effect due to a floor effect, rather than blocking per se (as discussed in a thesis on the same data; Hendrickx, 1997). In follow-up studies, blocking was no longer observed. In some contextual cueing studies, Beesley and Shanks (2012) similarly failed to observe evidence for blocking in an incidental learning visual search context, even with some evidence of *augmented* learning of blocked cues.

In a series of studies by Morís, Cobos, Luque, and López (2014) with human participants, blocking effects were found during a repetition priming task that did not require participants to use their knowledge of contingencies that were present in a preceding learning phase. Although these studies demonstrate that cue competition does not depend on the intentional *expression* of contingency knowledge, the learning itself was most likely intentional given that participants were asked to detect contingencies during the learning task. Hence, the studies of Morís et al. do not inform us about cue competition in incidental *learning* tasks.

Overshadowing studies are mixed. McLaren and colleagues (2014) observed impaired learning based on predictive colour cues when response sequences were predictable. Similarly, Endo and Takeda (2004) observed impaired learning based on distracter identities in a contextual cueing procedure when distracter configurations were redundantly predictive of the target location. Thus, it seems clear that when there are redundant cues of targets, one cue dimension may be used preferentially. Whether these findings are appropriately interpreted as evidence of overshadowing in incidental learning, however, is unclear given that the "overshadowed" cues were never tested in isolation from the "overshadowing" cues (i.e., the normal testing condition for overshadowing). This is likely due to the procedures used, where, for instance, one cannot present colour cues without a sequence of prior responses or present distracters with identities but no locations. Indeed, other work has shown that implicit sequence learning does not seem to be impaired by the presence of a highly salient cue (Cleeremans, 1997; Jiménez & Méndez, 2001; Mayr, 1996), inconsistent with overshadowing.

The main aim of our studies was to further explore cue competition in incidental learning tasks. We did not have clear predictions about what we would find. On the one hand, the association formation models discussed above (e.g., Rescorla & Wagner, 1972) should predict that cue competition will be present. It is generally assumed that association formation processes operate independently of the intention to learn. Therefore, if cue competition effects arise as the result of these processes, and if all other boundary conditions are met, then those effects should also arise in incidental learning tasks. On the other hand, some have argued that cue competition in humans (and perhaps in some non-human animals; see Beckers, Miller, De Houwer, & Urushihara, 2006) depends on deliberate reasoning processes (De Houwer, Beckers, & Vandorpe, 2005; Lovibond, 2003; see also, Vandorpe & De Houwer, 2005). For instance, the participant might reason about a blocking procedure in the following manner: "I already

know that Stimulus A produces the outcome. Now I see both Stimulus A and Stimulus X followed by the outcome. This might be because Stimulus A is present. Hence, I do not know whether Stimulus X *helps* in any way." Indeed, in the absence of information about situations in which Stimulus X occurs on its own, this is not an unreasonable conclusion to draw. Such uncertainty can explain reduced learning about Stimulus X in the blocked context compared to when X on its own is paired with the outcome. During an incidental learning task, participants may be less likely to deliberately reason about the task in such a way, reducing or eliminating cue competition effects.

We therefore set out to examine whether blocking and overshadowing can be observed within a particular incidental learning task: the color-word contingency learning task (Schmidt, Crump, Cheesman, & Besner, 2007). In the typical preparation, participants are presented a coloured word on each trial and are asked to respond to the print colour, typically with a key press (Schmidt & De Houwer, 2016a, 2016b) or oral response (Atalay & Misirlisoy, 2012; Forrin & MacLeod, 2017). The words in the task are colour-unrelated neutral words. Most critically, each word is presented most often in one colour (e.g., "look" 80% in blue), and only infrequently in other colours (e.g., "look" 20% in red or green). This produces *high contingency* trials, in which the word is presented in its most frequently paired colour (e.g., "look" in blue), and *low contingency* trials, in which the word is presented in an infrequently paired colour (e.g., "look" in red). Responses are faster and more accurate to high contingency trials relative to low contingency trials, indicating an influence of the contingency on performance.

This paradigm is particularly useful for present purposes, because almost 100% of participants show an effect in the correct direction (i.e., the effect is highly robust) even though the task does not require or even encourage participants to detect contingencies. As such, the task qualifies as an incidental learning task. Indeed, presence of the effect does not depend on contingency awareness. Although certain participants eventually become subjectively aware of the contingency manipulation, many others remain completely oblivious to it but still show a learning effect (Schmidt & De Houwer, 2012a, 2012b, 2012d; Forrin & MacLeod, 2017, 2018).

Colour-word contingency effects (perhaps poorly named) have been observed with dimensions other than words and colours. These include nonwords, shapes, and category members as distracters, and words as targets (Levin & Tzelgov, 2016; Schmidt, Augustinova, & De Houwer, 2018; Schmidt & De Houwer, 2012c; see also, the flanker contingency paradigm, Carlson & Flowers, 1996; J. Miller, 1987; Mordkoff, 1996; Mordkoff & Halterman, 2008). Levin and Tzelgov observed quite robust contingency effects with distracting shapes. In fact, the contingency effect for shapes during colour identification was even a bit larger than the effect for words. Thus, words and shapes can be used as our "Stimulus A" and "Stimulus X" dimensions (respectively or vice versa) in overshadowing and blocking experiments. These two dimensions are also useful in the sense that one can have: (a) word-only trials (coloured word, no shape), (b) shape-only trials (coloured shape, no word), and (c) compound stimulus trials (coloured word and shape).

Experiment 1

In Experiment 1, we tested for overshadowing in the colour-word contingency learning paradigm. The general trial procedure and example compound stimuli are illustrated in **Figure 1**. In particular, compound cues can be presented by printing a word inside a shape, both

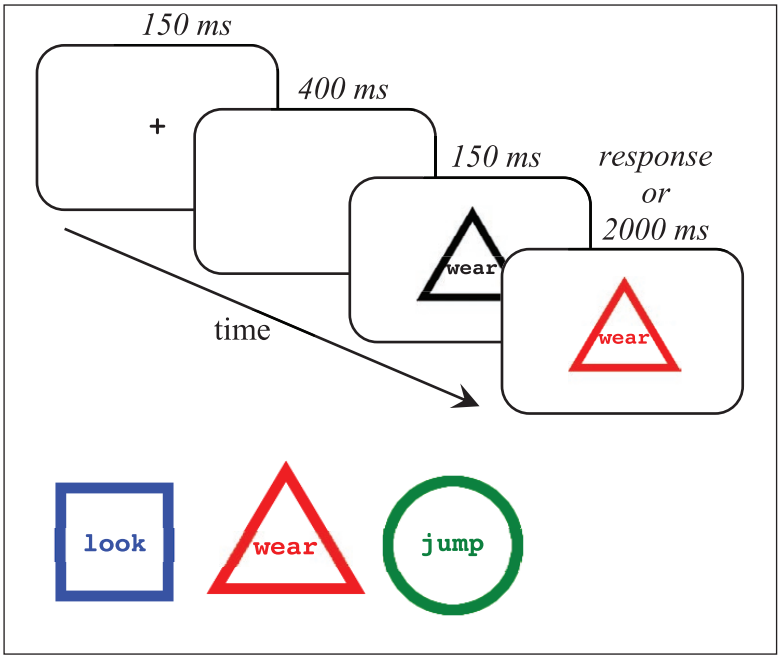

Figure 1: General trial procedure (top) and example compound stimuli (bottom). After a fixation cross and blank screen, a word-shape compound (or just a word or shape) is presented briefly in black, then changed to one of the target colours. See the online version of the article for a coloured figure.

coloured in the same hue. In the critical *compound-cue* condition, participants are consistently presented with both a word and a shape in a colour during a training phase. Each word-shape compound is presented most often in one colour (e.g., look-square in blue, wear-triangle in red, and jump-circle in green). During a test phase, participants are presented with a coloured word *or* a coloured shape and there are no longer contingencies between the distracting words/shapes and the colour (i.e., to prevent learning during test, comparable to traditional cue competition studies). Example relative stimulus frequencies by phase are presented in **Table 1**.

Using this procedure, we can test for contingency transfer effects for both words and shapes to see whether either stimulus dimension overshadows the other. If overshadowing proves to be less than complete, this would indicate that transfer from compound-cue training to (one or both of) the elements of the compound is possible during incidental learning in the colour-word contingency learning task. As control conditions, a *words-only* group of participants were trained only with words in colours (i.e., no shapes) and a *shapes-only* group were trained only with shapes in colours (i.e., no words). If some degree of overshadowing (perhaps not complete) is present, then we should expect contingency effects in the test phase to be smaller in the compound-cue group relative to the control groups. We also tested for subjective and objective awareness of the contingency manipulation to determine whether any observed overshadowing was related to awareness. More specifically, we examined whether learning effects for the overshadowed or blocked cue (i.e., X) depends on contingency awareness for the overshadowing or blocking cue (i.e., A). For instance, it may be that A only blocks X if participants have explicitly noticed the contingencies in the task. If so, the magnitude of the contingency effect at test for X should be inversely related to awareness. Note, however, that the issue of whether cue competition effects are influenced by contingency awareness is different from (and only indirectly related to) the issue of whether learning is incidental. For instance, contingency awareness can arise even if learning is incidental. We also registered contingency awareness as an additional dependent variable that might well provide evidence for overshadowing and blocking. That is, our "awareness" tests are also explicit measures of learning, used as the primary dependent variable in many human cue competition studies and also assessed here.

It is again important to stress that our task qualifies as an incidental learning procedure. That is, the relevant stimulus ("outcome") was always the colour (during both learning and test). Both words and shapes are, of course, predictive of the target response, but task irrelevant (i.e., not target stimuli) and the instructions said nothing related to the possibility of contingencies between colours and words or shapes. Thus, any learning of the word-response or shape-response contingencies is most likely incidental rather than the deliberate goal of the task.

Table 1: Experiment 1 example distracter-target contingencies for training and test.

	look	**wear**	**jump**	**□**	**△**	**○**	**look/□**	**wear/△**	**jump/○**
Training									
compound-cue									
blue							**8**	1	1
red							1	**8**	1
green							1	1	**8**
words-only									
blue	**8**	1	1						
red	1	**8**	1						
green	1	1	**8**						
shapes-only									
blue				**8**	1	1			
red				1	**8**	1			
green				1	1	**8**			
Test									
all groups									
blue	**1**	1	1	**1**	1	1			
red	1	**1**	1	1	**1**	1			
green	1	1	**1**	1	1	**1**			

Note: Example mappings only. Which words, shapes, or word-shape combinations went most frequently with which colours was counterbalanced across participants. High contingency items are indicated in bold.

Method

Participants. 139 participants were recruited online via prolific.ac for Experiment 1. The study itself was hosted on millisecond.com. We aimed for at least 40 participants per condition. With no directly comparable prior studies, this number was determined subjectively, but fixed a priori. There is some randomness in study completions after participant number assignment on millisecond.com, but participants were at least roughly distributed across the three conditions (52 combined cue, 44 words-only, and 43 shapes-only). An additional 12 submissions were deleted due to excessive errors (see Data Analysis). Another three incomplete submissions (the participant pressed Ctrl+Q to exit early) were also deleted. Participants were paid £1.5 for the experiment, which lasted approximately 15 minutes.

Apparatus. The experiment was programmed in Inquisit 5 and designed to work on a PC with an enforced 4:3 canvas aspect ratio. Participants responded by pressing the J, K, and L keys to blue, red, and green stimuli, respectively. The subjective awareness question was responded to with the Y or N keys for "yes" or "no."

Design. During the main task, either a word, shape, or word inside a shape was presented. The words were "look," "wear," and "jump" (in English). Words were presented in bold Courier New font at 4% screen size. The shapes were 18.75% screen width and 25% screen height (square with the 4:3 aspect ratio) and were the outline of a square, triangle, or circle. When the shape and word were both presented, the word fit inside the shape outline. The word and/or shape was first presented in black prior to changing to one of the target colours. This was done because it is known that pre-exposure of the distracter in this way boosts learning effects (Schmidt & De Houwer, 2016b). Cues preceding outcomes is also typical of many cue competition studies in both animals and humans (e.g., Beckers et al., 2006; Morís et al., 2014). The target colours were Inquisit/html "blue" (0,0,255), "red" (255,0,0), and "green" (0,128,0). Participants were randomly assigned to see only coloured words, only coloured shapes, or both a coloured word and shape (both same colour) during the training phase. When words were presented inside shapes, the same word always corresponded to the same shape, although which word was presented with which shape was randomly determined on a participant-by-participant basis.

During this training phase, each word/shape/compound was presented 80% of the time in one colour and 10% of the time in each of the remaining two colours. Which word/shape/compound was presented most often in which colour was randomly determined for each participant. In the final test phase, all participants saw both trials with coloured words only and trials with coloured shapes only. The contingencies were removed in the test phase, such that each word and shape was presented equally often in all colours. Thus, for the words-only and shapes-only groups, we expected a contingency effect during test only for the trained dimension (words and shapes, respectively) and no effect for the untrained dimension (i.e., there was nothing to learn; note that the each of the stimuli from the untrained dimension were yoked to one of the colours, with these cue-target "pairings" determined randomly for each participant). The compound-cue condition is the most interesting, in which we test to see (a) whether a test contingency effect is observed for both word and shape test trials, and (b) whether any such contingency effect is reduced relative to the two control groups. During an initial practice phase, the procedure was identical, except that a filled rectangle (8% screen width, 6% screen height) was presented (again, first in black, then in colour). There were 90 practice trials, selected randomly, followed by two training blocks (shapes-only, words-only, or compound-cue) of 150 trials each, and a test block of 90 trials. There were self-paced pauses between blocks.

Procedure. All stimuli were presented on a white (255,255,255) background. Each trial began with a fixation "+" in black (0,0,0) for 150 ms, followed by a blank screen for 400 ms. Next, the stimulus was presented in black for 150 ms before changing to one of the target colours. Responses could not be recorded prior to the colour change. Following a correct response, the next trial immediately began. Following an error or a trial in which participants failed to respond in 2000 ms, "XXX" was presented in black for 1000 ms.

After the main procedure, participants were asked for their subjective and objective contingency awareness. For the former, they were asked:

> This experiment was divided into three parts, starting with a practice phase (coloured rectangles) and ending with a test phase (coloured words or coloured shapes).
> During the rest of the experiment (middle), one [word/shape/word-shape combination] was presented most often in blue, another [word/shape/word-shape combination] was presented most often in red, and a third [word/shape/word-shape combination] was presented most often in green.
> Did you notice these regularities?

And for the objective awareness questions, they were first told:

> For the following questions, indicate in which colour you think that the following [word/shape/word-shape combination] was presented most often using the same keys as before.
> J-key: blue
> K-key: red
> L-key: green
> Guess if you are unsure.

This was followed by three randomly-ordered trials, each with one of the initially trained stimuli in black.

Data analysis. Both mean correct response times and error rates were assessed. Trials on which participants failed to respond were eliminated from analyses. Participants with more than 20% errors were also removed from analysis (see Participants). We supplement each key Null Hypothesis Significance Test (NHST) with Bayesian analyses in this and the following experiment, particularly

relevant for non-significant effects. In all cases, Bayesian tests were computed with a half normal distribution with a mean of zero and the effect in the control condition as the prior standard deviation (with an online Bayes calculator from Dienes, 2014). BF_{10} indicates evidence in favour of an effect and BF_{01} indicates evidence in favour of a null. We report the Bayes factor for the direction that the data favours (e.g., BF_{01} if the is more evidence for the null than for an effect). In line with convention, we refer to a $BF > 3$ as "moderate"[1] and a $BF > 10$ as "strong." Subjective and objective awareness questions were coded as percentage correct. We report correlations with nonparametric Spearman's ρ (which the lead author uses as standard practice), but the parametric Pearson's r produced similar results. The data and analysis scripts for this and the following experiment are available on the Open Science Framework (https://osf.io/ev7nh/).

Results

Training phase. For brevity, we only note that the contingency effect was highly robust for all participant groups during training (all $ps < .001$).

Control groups test. The response time data are presented in the left panel of **Figure 2**. First, we analyzed the two control groups to assure that robust contingency effects were observed during test for both words and shapes. In the words-only group, there was a contingency effect for words in response times (high: 670 ms; low: 701 ms; effect: 31 ms), $t(43) = 2.533$, $SE_{diff} = 12$, $p = .015$, $\eta^2 = .13$, but only a marginal effect in errors (high: 4.3%; low: 6.5%; effect: 2.2%), $t(43) = 1.969$, $SE_{diff} = 1.1$, $p = .055$, $\eta^2 = .08$. Predictably, there were no effects for shapes ($ts < 1$). The pattern was similar for the shapes-only group. The contingency effect was significant during test on shapes in response times (high: 616 ms; low: 658 ms; effect: 42 ms), $t(42) = 4.007$, $SE_{diff} = 10$, $p < .001$, $\eta^2 = .28$, but only marginally in errors (high: 3.9%; low: 5.9%; effect: 2.0%), $t(42) = 1.909$, $SE_{diff} = 1.1$, $p = .063$, $\eta^2 = .08$. Predictably, there were no effects for words ($ts \leq 1.500$).

Compound-cue group test. Next, we turn to the compound-cue group. There was a significant contingency effect in response times both for words (high: 634 ms; low: 670 ms; effect: 36 ms), $t(51) = 3.112$, $SE_{diff} = 12$, $p = .003$, $\eta^2 = .16$, and for shapes (high: 612 ms; low: 649 ms; effect: 37 ms), $t(51) = 3.711$, $SE_{diff} = 10$, $p < .001$, $\eta^2 = .21$. For errors, the contingency effect was non-significant for words (high: 6.3%; low: 6.0%; effect: –0.3%), $t(51) = 0.336$, $SE_{diff} = 0.9$, $p = .738$, $\eta^2 < .01$, and shapes (high: 5.3%; low: 7.1% ms; effect: 1.8% ms), $t(51) = 1.609$, $SE_{diff} = 1.1$, $p = .114$, $\eta^2 = .05$.

Cross-group comparisons. Robust contingency effects were observed in both training and test (albeit only for response times at test) in the compound-cue condition for both the words and the shapes. Thus, complete overshadowing was decidedly not observed. This might not be regarded as too surprising, as theories of cue competition typically do not propose that learning is prevented entirely for overshadowed/blocked cues. However, we next examined to what extent partial overshadowing might have been observed by directly comparing the compound-cue group to the controls using a series of ANOVAs comparing the contingency effect (high vs. low) by group (compound-cue vs. control) separately for word test trials and shape test trials. For the word test trials, we used the words-only group as controls; and for the shape test trials, we used the shapes-only group as controls. For response times, the ANOVA did not reveal a difference between compound-cue and words-only controls for word test trials, $F(1,94) = 0.107$, $MSE = 3369$, $p = .745$, $\eta_p^2 < .01$, or between compound-cue and shapes-only controls for shape test trials, $F(1,93) = 0.148$, $MSE = 2444$, $p = .701$, $\eta_p^2 < .01$. Across both, evidence for a true null was moderate in response times, $BF_{01} = 3.2$. For errors, there was a marginally larger effect for words-only controls relative to compound-cue, $F(1,94) = 3.088$, $MSE = 23.7$, $p = .082$, $\eta_p^2 = .03$, but not for shape-only controls, $F(1,93) = 0.012$, $MSE = 29.5$, $p = .915$, $\eta_p^2 < .01$. Across both, there was only anecdotal evidence for an effect, $BF_{10} = 1.4$.

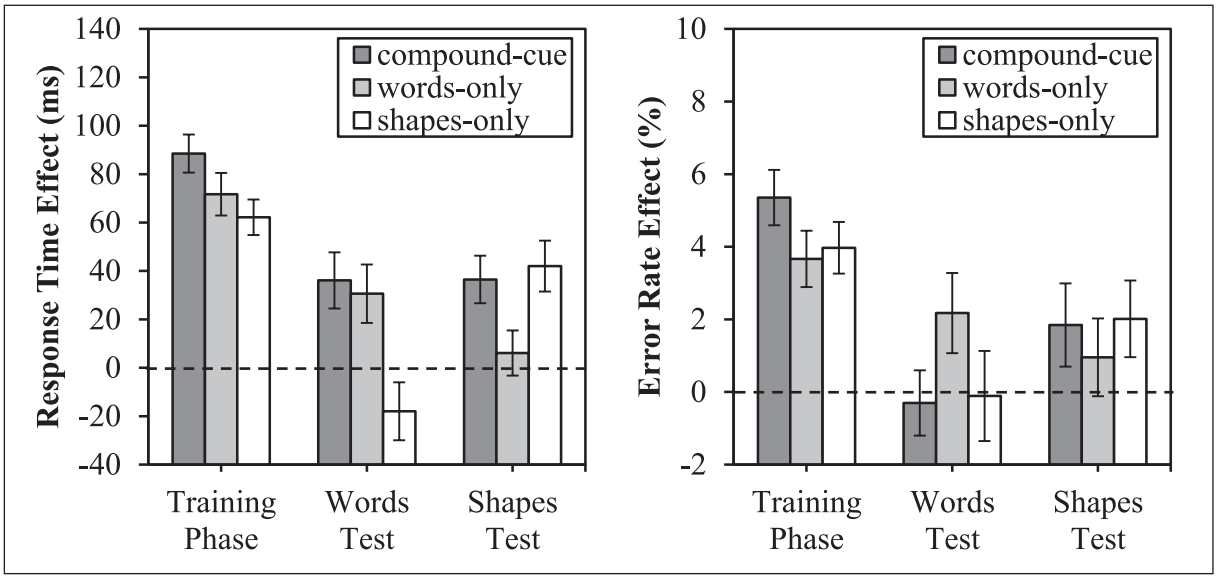

Figure 2: Experiment 1 response time (left) and percentage error (right) contingency effects (low – high contingency) as a function of group and phase, with standard error bars.

Thus, the error results, unlike response times, do not provide clear evidence that there was *no* overshadowing at all. It is also worth noting that a half-normal test is biased *against* inferences in favour of the null (i.e., a conservative test; see Dienes, 2014 for an explanation; see also, Dienes, Coulton, & Heather, 2018).

Contingency awareness. Overall, 52%, 50%, and 44% of participants in the compound-cue, words-only, and shapes-only conditions, respectively, reported being subjectively aware of the contingency manipulation. These percentages did not differ significantly, $F(2,136) = 0.292$, $MSE = 25$, $p = .747$, $\eta_p^2 < .01$. On the objective awareness test, participants were correct on 71%, 65%, and 64% of trials in the compound-cue, words-only, and shapes-only conditions, respectively. These percentages also did not differ significantly from each other, $F(2,136) = 0.441$, $MSE = 112$, $p = .644$, $\eta_p^2 < .01$, but all, of course, differed significantly from chance guessing (1/3; all ps $< .001$). Subjective and objective awareness significantly correlated, $\rho(137) = .399$, $p < .001$. Correlations with the response time training and test effects are presented in **Table 2**. As can be observed, there was some (albeit weak and inconsistent) evidence for larger effects with increased contingency awareness. In the absence of an overall overshadowing effect, no further analyses of the awareness data were conducted.

Discussion

In Experiment 1, no clear evidence for overshadowing was observed. That is: (a) a contingency effect was observed during the test phase for both shapes and words when shapes and words were trained together in compounds, and (b) this test effect for compound study was not smaller than the contingency effects observed for words and shapes after training of only words and shapes, respectively. Evidence for a true null (i.e., literally no overshadowing at all) was moderate for response times (despite the half-normal prior), but unclear for errors. In any case, it seems evident that a substantial overshadowing effect was not observed: test effects were quite robust for both elements of the compound stimulus. The present results might indicate that overshadowing is, more generally, absent (or very weak) with incidental learning. Of course, it could equally well be the case that incidental learning overshadowing effects are observable, only not with the present choice of stimulus dimensions (i.e., words and shapes). This study also demonstrates for the first time that it is possible to observe transfer of learning from compound (word-shape) stimuli to each of the elements of the compounds (i.e., words and shapes separately) in the colour-word contingency learning paradigm.

Experiment 2

In Experiment 2, we turn to blocking, using an approach similar to that of Experiment 1. In fact, the design of Experiment 2 was identical, except that instead of having three groups with two blocks of one stimulus type, there were three training groups: one that was presented only words during an initial *element training* block (words-first), a second that was presented only shapes during element training (shapes-first), and a third *overshadowing control* that was presented both shapes and words during training (identical to the compound cue group in Experiment 1). Both of the first two groups then proceeded to a *compound training* (blocking) phase, and all participants then completed a test block. The relative stimulus frequencies for the words-first element, shapes-first element, and compound training blocks were identical to those for the words-only, shapes-only, and compound training blocks of Experiment 1 (see **Table 1**). The test block was also identical. With this design, we can establish whether participants show a larger test effect for the initially trained dimension (i.e., "Stimulus A") than for the "blocked" dimension (i.e., "Stimulus X").

Because both words and shapes are used for both the blocking and blocked dimensions across subject conditions, an interaction between test item type (words vs. shapes) and condition (words-first vs. shapes-first) would indicate blocking. Note, too, that this is a rather liberal test for blocking, as a larger effect for Stimulus A over Stimulus X could potentially also be due to simply more training for Stimulus A. Thus, a failure to observe a difference between Stimulus A and X at test would argue even more strongly that blocking was not present. However, we also included an overshadowing group as a control.

We also included a manipulation of instructions. The intentional learning condition was identical to the incidental learning condition with one key exception: before starting the training phase, participants were presented with one additional instruction screen that explained that there would be a causal relation between the words/shapes and the colours they would be presented in. Participants were additionally instructed to

Table 2: Experiment 1 correlations between awareness and response time effects.

	Subjective awareness	Objective awareness
Compound-cue		
words test	$\rho(50) = -.106$, $p = .453$	$\rho(50) = .317$, $p = .022$
shapes test	$\rho(50) = .037$, $p = .794$	$\rho(50) = .008$, $p = .957$
Words-only		
words test	$\rho(42) = .304$, $p = .045$	$\rho(42) = .270$, $p = .076$
Shapes-only		
shapes test	$\rho(41) = -.011$, $p = .943$	$\rho(41) = -.082$, $p = .600$

intentionally learn these contingencies while performing the task. If deliberate (rather than just incidental) learning does play some role in cue competition effects, then we might be able to observe (stronger) evidence for cue competition effects with these instructions. We anticipated in advance that this manipulation should be more effective in producing cue competition effects, as it is known that human participants often produce such effects when deliberating over the contingencies (see D.R. Shanks, 2010, for a review).

Thus, our design included the within factors of contingency (high vs. low) and distracter type (words vs. shapes), as in Experiment 1, in addition to the between manipulations of training condition (words-first, shapes-first, and overshadowing control) and instruction condition (deliberate learning vs. incidental learning). We actually conducted four experiments from subsets of this design. In particular, we initially conducted Experiment 2a with only incidental learning and no overshadowing group. No blocking was found. Experiment 2b was then conducted as a more powerful replication with the addition of an overshadowing control group (only partially relevant in the absence of a blocking interaction). Again, no blocking was found. Experiment 2c was then conducted as a replication but with instructions to learn (reviewer requested). This time, there was partial evidence for blocking, similar to what we found in the combined data set. Finally, Experiment 2d was conducted as a replication (also reviewer requested) of the full design but now with random assignment of participants to the six different groups to verify that the observed effects did not depend on between-experiment comparisons. Predictably, no differences were observed between identical conditions across experiments (note that all four studies were identical, save for which between-group conditions were conducted in a given experiment). The studies were combined based on reviewer suggestions to condense presentation of the experiments and to improve statistical power. Given concerns regarding the selective use of data in between-group comparisons (or meta-analyses), it is important to note that we included all data that we ever collected on this topic in our analyses (see Vosgerau, Simonsohn, Nelson, & Simmons, 2018).

Method

Participants. There were 1510 participants total: 111 participants in Experiment 2a (51 words-first, 60 shapes-first; non-instructed), 250 in Experiment 2b (86 overshadowing, 88 words-first, 76 shapes-first; non-instructed), 293 in Experiment 2c (98 overshadowing, 99 words-first, 96 shapes-first; instructed), and 586 in Experiment 2d (105 and 100 overshadowing, 100 and 95 words-first, 86 and 100 shapes-first, non-instructed and instructed, respectively). As in the previous study, these sample sizes were determined a priori, Experiment 2a as a guess, Experiment 2b as a much larger replication, Experiment 2c to roughly match the instructed sample to the non-instructed sample, and Experiment 2d as a rough doubling of all six between-group conditions to ensure no differences were observed between a full-factorial experiment and the between-experiment differences we had already observed. Participants were recruited from the same pool as Experiment 1 and none participated in more than one experiment. An additional 6, 12, 17, and 14 participants, respectively, were excluded based on the same error cut-off as Experiment 1, and another 1, 4, 1, and 1 submissions, respectively, were excluded for not completing the study correctly (either by exiting with Ctrl+Q or skipping blocks with Ctrl+B).

Apparatus, design, procedure, and data analysis. The apparatus, design, procedure, and data analysis of Experiment 2 were identical in all respects to Experiment 1 with the following exceptions. First, there were six between-subject groups, made of the orthogonal combination of study condition (words-first, shapes-first, and overshadowing) and instruction condition (instructed vs. non-instructed). After the practice block (identical to Experiment 1), participants completed one block of 150 trials, identical to the words-only, shapes-only, or compound cue blocks used in Experiment 1. A second compound training (blocking) phase consisting of 150 trials followed this, and was the same as the compound-cue block in Experiment 1. The stimulus dimension that appeared in both blocks had the same contingencies in both (e.g., if "look" was presented most often in blue during element training, then "look" inside a, for instance, square was also presented most often in blue). The test block was also the same as in Experiment 1. With the words-first and shapes-first groups, we are primarily interested in the magnitude of the test effect for words and shapes as a function of whether words or shapes were the initially trained or blocked dimension. Thus, for the words-first group, words were the blocking dimension and shapes were the blocked dimension. The reverse was true for the shapes-first group. If blocking occurs, the contingency effect at test should be smaller for the blocked dimension.

The only difference in the procedure for instructed participants was an additional instruction page, which was added before the training phase:

> IMPORTANT
> Although your main task is still to respond to the colours, there will also be distracting stimuli (shapes and/or words). Each distracting stimulus might cause a specific colour most often. For instance, one word or shape might cause the colour to be blue most often, another red most often, and another green most often. Some stimuli might not be predictive at all. Try to learn which stimuli are predictive of which colours. At the end of the experiment, you will be tested to see whether you have correctly determined the pairings.

Experiment 2 additionally included an overshadowing group, which was identical to that in Experiment 1. The subjective awareness question was also slightly altered to the following (changes in italics):

This experiment was divided into *four* parts, starting with a practice phase (coloured rectangles) and ending with a test phase (coloured words or coloured shapes).

During the *second part of the experiment*, one [word/shape] was presented most often in blue, another [word/shape] was presented most often in red, and a third [word/shape] was presented most often in green.

Did you notice these regularities?

This was followed by a second subjective awareness question about the compound-cue phase:

During the third part of the experiment, one word-shape combination was presented most often in blue, another word-shape combination was presented most often in red, and a third word-shape combination was presented most often in green.

Did you notice these regularities?

Naturally, subjective awareness for the overshadowing group could only be probed for the word-shape compounds (i.e., there was no initially trained single dimension), so they had one less awareness question. The objective awareness instruction was also slightly modified (changes in italics) and each word and each shape was tested separately to get objective awareness measures for both the blocking and blocked dimensions:

For the following questions, indicate in which colour you think that the following *words and shapes were* presented most often using the same keys as before.
J-key: blue
K-key: red
L-key: green
Guess if you are unsure.

Results

Element and compound training phases. For brevity, we do not present results from the initial training phases of the study, but contingency effects were robust for all groups (all *p*s < .001).

Test phase response times. The results for the test phase are presented in **Figure 3**. Notably, the contingency effect is significant for both stimulus types in every condition of the experiment (all *p*s ≤ .001). We computed an ANOVA for stimulus type (word vs. shape) by contingency (high vs. low) by training condition (words-first vs. shapes-first vs. overshadowing) by instruction condition (non-instructed vs. instructed). Notably, the three-way interaction between

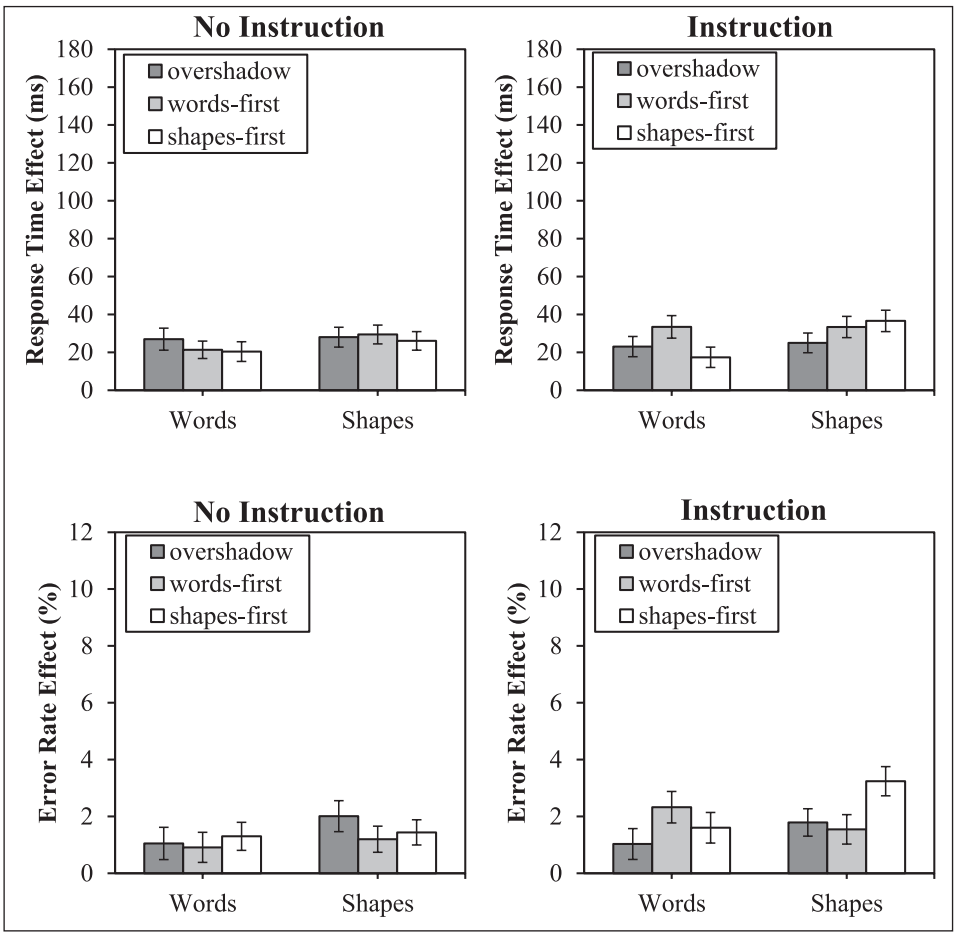

Figure 3: Experiment 2 response time (top) and percentage error (bottom) contingency effects (low – high contingency) as a function of group and stimulus type during the test phase, with standard error bars.

training group, stimulus item type, and contingency was not significant, $F(2,1234) = 1.229$, $MSE = 2715$, $p = .268$, $\eta_p^2 < .01$, indicating no robust blocking effect in response times. The four-way interaction including instruction group was also not significant, $F(2,1234) = 1.156$, $MSE = 2715$, $p = .282$, $\eta_p^2 < .01$. The latter two interactions were also not significant when excluding the overshadowing group, $F(1,847) = 1.388$, $MSE = 2691$, $p = .239$, $\eta_p^2 < .01$ and $F(1,847) = 2.315$, $MSE = 2691$, $p = .128$, $\eta_p^2 < .01$, respectively. Evidence for the interaction between instruction groups was only anecdotally in favour of a true larger blocking effect for instructed participants (22 ms), $BF_{10} = 2.2$.

Despite the lack of an interaction, the blocking interaction was tested separately for the non-instructed and instructed participants. In the non-instructed participants, the interaction was non-significant (–2 ms), $F(1,459) = 0.069$, $MSE = 2497$, $p = .792$, $\eta_p^2 < .01$, and the Bayes factor moderately favoured a true null blocking effect, $BF_{01} = 5.9$. There was further no difference between the overshadowed and blocked test effect, $t(650) = 0.388$, $SE_{diff} = 6$, $p = .698$, $\eta^2 < .01$, $BF_{01} = 3.3$. Thus, there was no evidence for blocking. For the instructed participants, the interaction was marginal (19 ms), $F(1,388) = 3.100$, $MSE = 2921$, $p = .079$, $\eta_p^2 < .01$, and with only anecdotal evidence in favour of a true blocking effect, $BF_{10} = 1.3$. However, there was an asymmetry in the blocking effect for instructed participants. In particular, the blocking effect in instructed participants was significant for words, $F(1,388) = 4.015$, $MSE = 3130$, $p = .046$, but not shapes, $F < 1$. The blocking effect was not significant for either distracter type in non-instructed participants, both Fs < 1. Thus, while there were some global hints of a true effect for instructed participants in response times (including a marginally significant 19 ms blocking interaction) and suggestive evidence for a larger effect in instructed participants, the response times did not prove definitive, unlike the remaining dependent variables to be discussed.

Test phase error rates. The errors produced a pattern of test results similar to those for the response times but evidence for all the crucial effects was moderate. The three-way interaction between training group, stimulus type, and contingency was not significant, $F(2,1234) = 1.670$, $MSE = 26$, $p = .197$, $\eta_p^2 < .01$, indicating that the overall blocking effect was not significant, also not when excluding the overshadowing group, $F(1,847) = 2.621$, $MSE = 26$, $p = .106$, $\eta_p^2 < .01$. The four-way interaction including instruction condition was also not significant, $F(2,1234) = 1.705$, $MSE = 26$, $p = .192$, $\eta_p^2 < .01$, though it was marginal when excluding the overshadowing group, $F(1,847) = 3.362$, $MSE = 26$, $p = .067$, $\eta_p^2 < .01$, indicating a larger blocking effect for instructed participants. However, Bayesian evidence was moderately in favour of a larger blocking effect in instructed participants (2.6%), $BF_{10} = 3.3$.

The blocking interaction was then tested separately for the non-instructed and instructed participants. In the non-instructed participants, the interaction was non-significant (–0.2%), $F(1,459) = 0.027$, $MSE = 25$, $p = .871$, $\eta_p^2 < .01$ and the Bayes factor was moderately in favour of a true null blocking effect, $BF_{01} = 3.1$. There was further no difference between the test effect for the blocked dimension versus the overshadowing control, $t(650) = 0.484$, $SE_{diff} = 0.6$, $p = .628$, $\eta^2 < .01$, $BF_{01} = 1.9$. For the instructed participants, the interaction was significant (2.4%), $F(1,388) = 5.178$, $MSE = 28$, $p = .023$, $\eta_p^2 = .01$, and Bayesian evidence was moderately in favour of a true blocking effect, $BF_{10} = 4.5$. As in the response times, there was an asymmetry in the blocking effect for instructed participants, with a significant blocking effect for shapes, $F(1,388) = 5.410$, $MSE = 26$, $p = .021$, $\eta_p^2 = .01$, but not words, $F < 1$. The blocking effect was not significant for either distracter type in non-instructed participants, both Fs < 1. Thus, the errors provide clearer evidence for instruction-mediated blocking than the response times.

Overshadowing. Strictly speaking, Experiment 2 did not contain the standard contrasts for overshadowing (as in Experiment 1). However, the experiment did contain the overshadowing condition (identical to Experiment 1) in addition to two conditions in which elements were trained alone first (i.e., words-first and shapes-first). Thus, the mean test contingency effect for both distracter types in the overshadowing condition can be compared to the test contingency effect for the initially-trained dimension in the other two conditions (i.e., words in words-first and shapes in shapes-first) as a measure of overshadowing.[2] For non-instructed participants, the overshadowing effect was not significant in both response times, $t(650) = 0.665$, $SE_{diff} = 6$, $p = .507$, $\eta^2 < .01$, and errors, $t(650) = 0.610$, $SE_{diff} = .6$, $p = .507$, $\eta^2 < .01$, with strong evidence for a true null in response times, $BF_{01} = 6.5$, and moderate support for a true null in errors, $BF_{01} = 3.2$. However, for instructed participants the overshadowing effect was marginal in response times, $t(586) = 1.738$, $SE_{diff} = 6$, $p = .507$, $\eta^2 < .01$, and significant in errors, $t(586) = 2.325$, $SE_{diff} = .6$, $p = .020$, $\eta^2 < .01$. Bayesian evidence was anecdotally in favour of a true effect for response times, $BF_{10} = 1.5$, and moderately favoured a true effect for errors, $BF_{10} = 5.5$. Thus, also for overshadowing, an effect is observable, but only in instructed participants.

Contingency awareness. Overall, 42%, 41%, and 54% of non-instructed participants and 73%, 70%, and 76% of instructed participants in the words-first, shapes-first, and overshadowing conditions, respectively, reported being subjectively aware of the contingency manipulation during the element training phase. Awareness of the contingencies by non-instructed participants in the compound training phase was 35% and 33%, respectively, for the words-first and shapes-first conditions, and 49% and 57% for instructed participants. Subjective awareness for the blocked dimension was significantly decreased relative to the blocking dimension in non-instructed participants, $t(460) = 3.732$, $SE_{diff} = 8$, $p < .001$, $\eta^2 = .03$, and instructed participants, $t(389) = 7.635$, $SE_{diff} = 18$, $p < .001$, $\eta^2 = .13$. This blocking effect was significantly larger in instructed participants, $F(1,849) = 10.460$, $MSE = 2200$, $p = .001$, $\eta_p^2 = .01$, with strong evidence for a true effect, $BF_{10} = 55.1$.

On the objective awareness test, non-instructed participants were correct on 56% and 56% of trials testing the *blocking* (i.e., initially trained dimension) in the words-first and shapes-first conditions, respectively, and 51% and 52% for the *blocked* dimension. Objective awareness

was 58% and 57% for words and shapes, respectively, for participants in the overshadowing condition. For instructed participants, these rates were 68%, 73%, 62%, 58%, 71%, and 70%, respectively. All of these objective awareness scores were, of course, above chance guessing (1/3; all *p*s < .001). Objective ratings on the blocking dimension were significantly higher than on the blocked dimension for both non-instructed participants, $t(460) = 2.139$, $SE_{diff} = 6$, $p = .033$, $\eta^2 < .01$, and instructed participants, $t(389) = 5.087$, $SE_{diff} = 11$, $p < .001$, $\eta^2 = .06$, and this blocking effect was significantly larger in instructed participants, $F(1,849) = 4.132$, $MSE = 1982$, $p = .042$, $\eta_p^2 < .01$, with moderate evidence for a true effect, $BF_{10} = 3.6$.

Correlations with the response time effects during the test phase are presented in **Table 3**. Although awareness was correlated with effects during active learning (not presented) test contingency effects were not robustly correlated with awareness. Indeed, the only correlation to survive a Bonferroni-Holm correction is rather difficult to interpret (i.e., objective awareness of the words contingency positively correlating with the shapes effect in the shapes-first condition). There were no clear indications of awareness of blocking contingencies negatively correlating with the magnitude of blocked test items. That is, awareness of the Stimulus A contingencies did not seem to be directly related to diminished contingency effects for Stimulus X.

Discussion

In Experiment 2, we did not observe robust evidence for blocking in non-instructed participants in response times or errors. In particular: (a) a contingency effect was observed for the "blocked" dimension (e.g., shapes in the words-first condition) for both training conditions (words-first and shapes-first), and (b) this contingency effect for the "blocked" dimension was not significantly smaller than the contingency effect for the trained/blocking dimension. Bayesian evidence moderately favoured a true null in both response times and errors. Of course, it always remains possible that a blocking effect did exist that is so vanishingly small that our conservative half-normal Bayes prior incorrectly inferred a true null, but we can conclude that the present results provide little evidence for blocking in a purely incidental learning task.

Of course, the presence or absence of blocking inevitably depends on a number of factors and the present experiment tested one of those factors. Within the participants that we instructed to explicitly learn contingencies in the task, significant blocking effects emerged in response times and errors. This blocking effect was only present for words in response times, however, and for shapes in the error rates. Bayesian evidence for blocking was only clear in errors with evidence in support of both a true effect for instructed participants that was also larger than that for non-instructed participants. The same trends were present in response times, but only anecdotally. Additionally, robust blocking effects for instructed participants showed up in the subjective and objective awareness data, with participants showing increased awareness of the blocking contingency than the blocked contingency. Interestingly, the same effect was observed in non-instructed participants, but the effect was significantly larger in instructed participants. In sum, we found clear evidence for blocking in a deliberate learning task on various dependent measures. Some tests also revealed a significant effect of type of task (incidental or deliberate) on blocking, although the evidence for this was mixed.

Finally, in line with the results of Experiment 1, no clear evidence for overshadowing was found for non-instructed participants, with clear Bayesian evidence for a true null. More generally, it seems clear that robust *learning* about stimuli that were "blocked" or "overshadowed" was observed in non-instructed participants, which was, at minimum, very closely comparable to learning about "blocking" or "non-overshadowed" stimuli. Instructed participants, however, showed a robust overshadowing effect in errors, albeit with only anecdotal/marginal evidence for a true effect in response times.

General Discussion

In the present report, we aimed to examine cue competition in an incidental learning paradigm. At the outset of this research, we had no clear predictions.

Table 3: Experiment 2 correlations between awareness and response time effects.

	Subjective awareness		Objective awareness	
	training	**blocking**	**words**	**shapes**
Overshadow				
words test	$\rho(387) = .122$, $p = .016$		$\rho(387) = .077$, $p = .130$	$\rho(387) = -.011$, $p = .836$
shapes test	$\rho(387) = .112$, $p = .027$		$\rho(387) = .032$, $p = .531$	$\rho(387) = .142$, $p = .005$
Words-first				
words test	$\rho(431) = .138$, $p = .004$	$\rho(431) = .097$, $p = .044$	$\rho(431) = .158$, $p < .001$	$\rho(431) = .112$, $p = .020$
shapes test	$\rho(431) = .054$, $p = .263$	$\rho(431) = .021$, $p = .663$	$\rho(431) = -.077$, $p = .109$	$\rho(431) = .080$, $p = .098$
Shapes-first				
words test	$\rho(416) = .084$, $p = .087$	$\rho(416) = .107$, $p = .029$	$\rho(416) = .062$, $p = .209$	$\rho(416) = .043$, $p = .385$
shapes test	$\rho(416) = -.003$, $p = .947$	$\rho(416) = .037$, $p = .452$	$\rho(416) = .150$, $p = .002$	$\rho(416) = .052$, $p = .292$

On the one hand, we are convinced by the overwhelming evidence that blocking and overshadowing are genuine phenomena and found it quite plausible that such effects might be observed in an incidental learning procedure. On the other hand, models that attribute cue competition to deliberative reasoning processes (e.g., De Houwer et al., 2005) do not predict cue competition in incidental learning and we also found very few studies in the literature that had examined cue competition effects in incidental learning tasks (which seemed strange to us given the large concentration of researchers focusing on cue competition and on incidental learning, with many publishing in both literatures).

As mentioned earlier, the colour-word contingency learning paradigm is quite useful, as it produces highly robust learning effects in a paradigm in which the predictive stimuli are task irrelevant. Indeed, many participants are completely oblivious to the contingency manipulation, but nevertheless produce robust contingency effects. These contingency effects remained very robust during our test phases (i.e., where the contingency was no longer present). However, we did not observe clear evidence in the response times or errors for overshadowing or blocking in our experiments when participants were not given explicit instructions to learn the regularities. It is important to stress that this is not a "simple" null (which can often be ambiguous): *robust* learning effects were observed, including for the blocked/overshadowed cues. Put differently, there was a robust effect to block or overshadow, but this did not occur.

Given our failures to observe blocking and overshadowing in our initial attempts, in Experiment 2 we also tested whether cue competition effects could be observed in the same paradigm when participants were informed in advance that the distracting stimuli are predictive of the target colours (see also, Schmidt & De Houwer, 2012a), with the encouragement to try to discover said contingencies. Finding evidence for cue competition in a deliberate learning version of the same task would indicate that the absence of cue competition in the standard (incidental) version is not due to some trivial aspect of the procedure (discussed further below). The results *did* indeed provide clear evidence for cue competition for participants who were given the deliberate learning instructions. Blocking was significant in response times, albeit only for words. The reason that shapes were more effective at blocking words than the reverse is unclear, but might indicate a greater saliency of shapes. This is also consistent with the generally larger contingency effects for shapes. Blocking was also significant in errors, and robustly larger than the null effect for non-instructed participants.

We did observe some evidence for blocking in the rating (i.e., contingency awareness) data for non-instructed participants, but this effect was robustly smaller than that for instructed participants. However, that blocking effects *were* observed in rating data for non-instructed participants but not in response time and error data is an interesting dissociation. That such effects are not observed during the mindless response time task, but are observed when participants are asked to make an explicit decision about the contingencies may be considered consistent with the notion that reasoning processes are necessary to produce cue competition. With regard to the data on overshadowing, trends toward overshadowing were observed in the response times for instructed participants, but not robustly. However, there was a significant overshadowing effect in error rates, again only in instructed participants.

In sum, we found virtually no evidence for cue competition in a widely used incidental learning task. On the contrary, Bayesian analyses repeatedly revealed moderate evidence for the null. This absence of cue competition was not due to trivial aspects of the procedure because moderate evidence for cue competition was found in the same task when instructions encouraged participants to learn the contingencies. Finally, we obtained some evidence that the intention to learn is a moderator of cue competition in that task instructions had a significant impact on the magnitude of blocking in some of the relevant comparisons (e.g., moderate/strong Bayesian evidence in errors, and in subjective and objective ratings).

When taken together, these findings are consistent with the notion that explicit learning of contingencies is an important factor in producing cue competition. That is, when participants are encouraged to strategically reason about co-occurrences of stimuli (including compounds) with outcomes, then explicit decision processes either boost or are directly responsible for cue competition effects, such as blocking (but see De Houwer et al., 2005 for a discussion of the boundary conditions under which deliberate reasoning processes can produce blocking). It does seem clear from the present results and those of Morís and colleagues (2014), discussed earlier, that cue competition effects can be observed during a task in which retrieval is automatic. It could be, however, that incidental *learning* in insufficient or less potent.

The fact that cue competition effects *were* observed with the present materials with deliberate but not incidental learning suggests that during blocking and overshadowing experiments the Stimulus X contingencies are (e.g., implicitly) learned, but counteracted via explicit decision processes. For instance, the fact that learning of the Stimulus X-outcome relation occurs without explicit instructions during blocking suggests that passive acquisition of associations during blocking is not impeded. However, once the participant is explicitly instructed to learn the contingencies, the influence of this passive learning on performance is no longer observed, perhaps indicating suppression of the knowledge of the pairings by explicit decisional processes. This notion bears some resemblance to retrieval-based theories of cue competition effects, which argue that acquired contingencies are suppressed at retrieval test (see Kaufman & Bolles, 1981; Matzel, Schachtman, & Miller, 1985; see R. R. Miller & Witnauer, 2016, for a review; but see, Holland, 1999). As subtle variants of this notion, it could be cue competition depends on more difficult attentional focus during deliberate learning or that cue competition effects require active consideration of causation/prediction.

Although the present results do suggest that intentional learning magnifies cue competition effects, it could still be that cue competition effects can be produced in incidental learning procedures. However, such effects may simply be smaller in incidental learning and we may not have had sufficient power to detect such an effect (e.g., Bayesian evidence for a true null does not rule out a vanishingly small effect). Relatedly, the failure to observe cue competition effects in non-instructed participants may have also been due not only to the unintentional nature of the learning task but also to other factors. Indeed, the present results are interesting in light of a recent report by Maes and colleagues (2016). In a series of 15 experiments, those authors consistently failed to observe blocking in animals. This suggests that cue competition effects in general are subject to multiple boundary conditions. It still remains quite unclear, however, *what* the limiting conditions of blocking (and overshadowing) effects are, with many seemingly contradictory findings (for a discussion, see Maes et al., 2018). Nevertheless, it is possible that an altered design would produce evidence for cue competition effects also in incidental learning tasks.

One factor that might influence the coming and going of blocking and overshadowing is similarity in stimulus modality. In compound-cue theories (Kehoe & Gormezano, 1980; Pearce, 1987, 1994, 2002), stimulus compounds (e.g., AX) are processed *configurally* (i.e., as one stimulus) and cue competition represents a failure to transfer learning, for instance, from AX to X (see also, Kinder & Lachnit, 2003; Soto, Gershman, & Niv, 2014; Wagner, 2003). According to Soto (2018), this transfer will be much stronger for same modality stimuli. Blocking has been observed within stimulus modalities (e.g., sounds in Beckers et al., 2006; Blaisdell, Gunther, & Miller, 1999; Wheeler, Beckers, & Miller, 2008), including in the present Experiment 2 with instructed participants. However, cue competition might emerge even during incidental learning with different modality stimuli. Future research might explore modality effects with the present paradigm by mixing cue modalities (e.g., words and tones) or even *target* modalities (colour in the present report, also visual).

It is also conceivable that the magnitude of blocking might depend on how overtrained the initial contingencies were. For instance, a blocking effect might emerge (even with incidental learning) if the initial training phase is lengthened (i.e., Stimulus A must be *strongly* trained in order to block Stimulus X). Conversely, for both blocking and overshadowing, cue competition might be larger with a shorter combined cue phase. That is, learning may *eventually* occur for an initially overshadowed or blocked dimension. These considerations cannot explain why we were able to observe effects in instructed participants with these same durations, of course, but exploration of different block durations might be an interesting avenue for future research on incidental cue competition.

In summary, the present report raises several interesting questions about cue competition effects in both incidental and non-incidental learning procedures. The lack of overshadowing and blocking in the present experiments without deliberate learning instructions is surprising, and hints at several useful avenues for future research. Further, our novel procedure for studying cue competition under incidental learning conditions could be a very useful tool for exploring the boundary conditions of cue competition effects. Our second experiment already suggests one important factor: intentional learning. Whether intentional learning and/or subsequent explicit decision processes are necessary for cue competition or merely boost otherwise small effects remains an open question, however.

Data Accessibility Statement

The data and analysis scripts for this and the following experiment are available on the Open Science Framework (https://osf.io/ev7nh/).

Notes

[1] The term "substantial" is often used instead, but is slightly confusing as it means "of substance" rather than "very large." The "moderate" criterion roughly corresponds to "significant" in NHST, with "strong" being an even more restrictive criterion.

[2] Note that the second dimension was eventually added during the blocking phase for the words-first and shapes-first conditions, so this can be regarded as a conservative (likely null-biased) measure of overshadowing. As such, the non-significant effects for non-instructed participants can be taken with a grain of salt, but the significant effects for instructed participants are perhaps less problematic.

Funding Information

This work was supported by the French "Investissements d'Avenir" program, project ISITE-BFC (contract ANR15-IDEX-0003) to James R. Schmidt and Grant BOF16/MET_V/002 of Ghent University to Jan De Houwer.

Competing Interests

The authors have no competing interests to declare.

Author Contributions

- Contributed to conception and design: JRS, JD
- Contributed to acquisition of data: JRS
- Contributed to analysis and interpretation of data: JRS
- Drafted and/or revised the article: JRS, JD
- Approved the submitted version for publication: JRS, JD

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Peer review comments
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How to cite this article: Schmidt, J. R., & De Houwer, J. (2019). Cue Competition and Incidental Learning: No Blocking or Overshadowing in the Colour-Word Contingency Learning Procedure Without Instructions to Learn. *Collabra: Psychology,* 5(1): 15. DOI: https://doi.org/10.1525/collabra.236

Senior Editor: Rolf Zwaan

Editor: Jim Grange

Submitted: 08 February 2019 **Accepted:** 11 March 2019 **Published:** 09 April 2019

UNIVERSITY of CALIFORNIA PRESS | Collabra: Psychology

Collabra: Psychology is a peer-reviewed open access journal published by University of California Press.

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