**Context modulation of learned attention deployment**

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**Abstract**

In three experiments, we investigated contextual control of attention in human discrimination learning. In each experiment, participants initially received discrimination training in which cues from Dimension A were relevant in Context 1, but irrelevant in Context 2, while cues from Dimension B were irrelevant in Context 1, but relevant in Context 2. In Experiment 1, the same cues from each dimension were used in Contexts 1 and 2, while in Experiments 2 and 3, the cues from each dimension were changed across contexts. In each experiment, participants were subsequently shifted to a transfer discrimination involving novel cues from either dimension in order to assess contextual control of attention. In Experiment 1, measures of eye-gaze during the transfer discrimination revealed that Dimension A received more attention than Dimension B in Context 1, while the reverse occurred in Context 2. Corresponding results indicating contextual control of attention were found in Experiments 2 and 3, which used the speed of learning (associability) as an indirect marker of learned attentional changes. Implications of our results for current theories of learning and attention are discussed.

Keywords: attention, context, discrimination learning, humans

Prior experience changes the ease with which we learn about a stimulus. Such changes in associability are demonstrated, for instance, by the intra-dimensional/extra-dimensional shift (ID/ED shift) effect (for a survey, see Le Pelley, 2004; Le Pelley, Mitchell, Beesley, George, & Wills, 2016; Pearce & Mackintosh, 2010). In one demonstration of the effect, Uengoer and Lachnit (2012) trained human participants to categorize stimuli varying on two dimensions (e.g., color and shape). For the solution of the discrimination problem, two values from one dimension were relevant as they consistently signaled the category of the stimuli, while two values from another dimension were irrelevant by being unrelated to category membership (e.g., red squares and red circles belonged to one category, while blue squares and blue circles belonged to another category). Subsequently, participants received a second discrimination in which the stimuli were characterized by novel values from the previous dimensions (e.g., green, yellow; triangle, diamond). Uengoer and Lachnit observed that the second discrimination was acquired more rapidly when based on values from the dimension that had previously been trained as relevant for the first discrimination (ID shift; e.g., colors green and yellow signaled category membership) than when based on the previously irrelevant dimension (ED shift; e.g., shapes triangle and diamond signaled category membership). This effect suggests that training of the initial discrimination resulted in more attention being paid to stimulus features belonging to the relevant than the irrelevant dimension, and that these changes in attention were transferred to the stimuli of the second discrimination, which facilitated acquisition of the ID shift discrimination compared to the ED shift condition (e.g., Mackintosh, 1975). The assumption that discrimination learning involves changes in attention to relevant and irrelevant stimuli is further supported by studies using measures of eye-gaze (e.g., Le Pelley, Beesley, & Griffiths, 2011; Lucke, Lachnit, Koenig, & Uengoer, 2013; Mitchell, Griffiths, Seetoo, & Lovibond, 2012) and neurophysiological markers (e.g., Feldmann-Wüstefeld, Uengoer, & Schubö, 2015).

Uengoer, Lachnit, Lotz, Koenig, and Pearce (2013) and George and Kruschke (2012) demonstrated that changes in associability can come under the control of contextual stimuli. In their experiments, participants were initially trained with a conditional discrimination involving two contexts. In Context 1, the discrimination was solvable on the basis of cues from Dimension A, while cues from Dimension B were irrelevant. In Context 2, the same set of cues comprised a discrimination for which Dimension B was relevant and Dimension A was irrelevant. Following this training, participants received a second discrimination in which novel cues from Dimension A were relevant, and novel cues from Dimension B were irrelevant. Participants were found to master the second discrimination more rapidly when training was given in Context 1 than when trained in Context 2. This finding indicates that the associability of (and, by inference, attention to) the stimuli varied according to the context in which they were presented. More precisely, it suggests that in Context 1, cues from Dimension A possessed greater associability than those from Dimension B, while in Context 2, the opposite applied - greater associability of Dimension B than of Dimension A.

In real life, humans and other animals deal with a vast variety of tasks, and stimuli that are relevant to accomplish a certain task may be unimportant for successful performance in another situation. For instance, when looking for a friend in a crowd of people, it may be advantageous to attend to clothing color, while, when searching for a book in a crowded library, clothing color provides no useful information. In view of this, the ability of context-specific attention (George & Kruschke, 2012; Uengoer et al., 2013) appears to be an obvious way in which organisms may deal with the ever-changing demands in their environments. However, many theories of learning and attention neglected the context as a modulator for stimulus processing (e.g., Kruschke, 1992; Le Pelley, 2004; Mackintosh, 1975; Pearce, George, & Redhead, 1998; Pearce & Mackintosh, 2010). Thus, these models are unable to capture the possibility that a stimulus receives considerable attention in one context, while being ignored in a different context.

The aim of the present study was twofold. One aim was to assess the validity of the conclusion in terms of context-specific attention drawn from the studies by Uengoer et al. (2013) and George and Kruschke (2012). In these two previous studies, contextual control of attention during initial training was inferred from subsequent differences in learning rates. If this inference is valid, then it should be possible to arrive at the same conclusion using other indicators of attention. Therefore, Experiment 1 was based on the procedures used by Uengoer et al. (2013) and George and Kruschke (2012), but in addition, included measures of eye-gaze as a marker of attention. By means of this measure, we investigated whether training a stimulus as relevant in one context, but as irrelevant in another context, results in corresponding changes in overt attention, and we explored whether changes in overt attention are transferred to novel stimuli in a context-specific manner.

A second aim of the present study, which was pursued by Experiments 2 and 3, was to investigate the role of associative interference for the formation of context-specific changes in associability. Consider a study by Griffiths and Le Pelley (2009), which provided no evidence that changes in associability are modulated by contextual changes using a blocking procedure. In a typical blocking experiment (Kamin, 1968), an individual stimulus is repeatedly paired with an outcome (A+) before presented in compound with a second stimulus B. This compound stimulus is also repeatedly followed by the outcome (AB+). During a final test, it can be observed that responding to Stimulus B by itself is weaker than for a control group in which pre-training with Stimulus A was omitted. It is said that learning about Stimulus B was blocked due to prior training of Stimulus A.

For humans and for non-human animals, it was found that subsequent learning about a previously blocked stimulus was retarded (Kruschke & Blair, 2000; Mackintosh & Turner, 1971) indicating that blocking involves a reduction of attention to the blocked stimulus. On the basis of this finding, Griffiths and Le Pelley (2009) examined whether the rate of new learning about a previously blocked stimulus can be modulated by contextual manipulations.

During an initial phase, participants received training in which individual stimuli were paired with an outcome (e. g., A→O1, C→O1, E→O1). During a second phase, each of the stimuli was presented in compound with a novel stimulus, and these compounds were also paired with the outcome (e. g., AB→O1, CD→O1, EF→O1). Following this blocking treatment, participants received a third phase of training in which stimulus compounds signaled a new outcome. Some of these compounds comprised stimuli that had already been presented together during Phase 2 (old compounds, e. g., AB), whereas other compounds comprised one blocking stimulus and one blocked stimulus that had been trained on separate occasions during the preceding phase (new compounds, e. g., ED). Griffiths and Le Pelley observed that learning about the new outcome in Phase 3 proceeded slower for the blocked stimuli (e. g., B, D) than for the blocking stimuli (e. g., A, E) indicating that their blocking procedure led to a decrease in attention to the blocked stimuli. More crucially, they also reported that the impairment of learning about the blocked stimuli in Phase 3 was independent of whether the blocked stimuli were presented in old compounds or in new compounds. This finding is consistent with the view that attention to a stimulus is not controlled by the context in which it appears.

In the experiment by Griffiths and Le Pelley (2009), stimuli were either trained as predictive (blocking stimuli) or as redundant (blocked stimuli). Thus, the significance of the stimuli remained unchanged throughout the blocking treatment. In contrast, Uengoer et al. (2013) and George and Kruschke (2012) used conditional discriminations in which the stimuli were explicitly trained as both relevant and irrelevant depending on the context. Uengoer et al. suggested that such explicit training in which the significance of a stimulus changes according to context may be necessary for the formation of contextual control of stimulus associability (for a similar suggestion, see George & Kruschke). The aim of Experiments 2 and 3 was to test this proposal.

**Experiment 1**

In Experiment 1, we recorded gaze position as a measure of overt attention in order to examine the contextual control of attention. In each learning trial (see Figure 1), participants were presented with a stimulus array consisting of two cue cues from two dimensions, A and B (letter and shape), presented above and below fixation, and two peripheral stimuli of different colors to the left and the right of fixation (context and control stimulus). The control stimulus, which was the same on every trial, served as a reference to assess eye gaze toward the context.

The learning schedule of Experiment 1 is shown in Table 1. In Stage 1, participants received a conditional discrimination involving two contexts. In Context 1, correct responding (R1 or R2) was predictable on the basis of two cues from Dimension A (A1 and A2), while two cues from Dimension B (B1 and B2) were irrelevant. In Context 2, the same set of cues comprised a discrimination that was solvable on the basis of the cues from Dimension B, while those from Dimension A were irrelevant.

In Stage 2, which used another set of cues from each dimension, participants were trained with two optional-shift discriminations. In Context 1, the compounds A3B3 and A4B4 were related to the responses R1 and R2, respectively, and in Context 2, R1 and R2 were signaled by the compounds A5B5 and A6B6, respectively. Thus, in Stage 2, the discrimination in each context was optional in the sense that it is solvable on the basis of either Dimension A or Dimension B, or both.

If training of the conditional discrimination in Stage 1 results in context-dependent attention that is transferred to the cues from Stage 2, then Dimension A will receive more overt attention than Dimension B in case of the optional-shift discrimination in Context 1 of Stage 2, while Dimension B will capture more overt attention than Dimension A when participants work on the optional-shift discrimination in Context 2 of the second stage.

**Method**

**Participants.** Thirty-three students of the Philipps-Universität Marburg participated in the experiment and received either course credit or payment. All participants had normal or corrected-to-normal vision. The data of three participants were excluded from further analysis because of signal noise or excessive blinking. The data of four participants were excluded because their response accuracy did not exceed 60% in at least one of the two contexts in Stage 1. Of the remaining participants 21 were female and 5 were male. Their age ranged from 18 to 29 with a median of 21.

**Apparatus.** Testing took place in a sound-attenuated, dimmed room. Monocular eye movements were recorded using an infrared video-based eye tracker (Eyelink 2000, SR-Research) that sampled position of pupil and corneal reflection at 1000Hz. Sampling of the left versus right eye was counterbalanced across participants. The eye tracker was calibrated with a 9-point grid of calibration targets. The calibration procedure was rerun until subsequent validation confirmed an average calibration error < 0.5°. The eye tracker restrained the participants head via chin and forehead rests and was table-mounted in front of a 22”-CRT monitor (Iiyama, Vision Master Pro514) yielding an eye-to-screen-distance of 78 cm. Stimulus delivery was controlled by Presentation® software (www.neurobs.com).

**Stimuli.** Visual stimuli were presented on a 60% grey background. Two colored squares were shown 130mm to the left and to the right of fixation respectively and represented the context and control stimuli. Colors (R, G, B) were chosen from a set of red (233, 198, 175), green (198, 233, 175), and blue (170, 204, 255). A letter and a geometric shape were shown 130mm above and below central fixation to represent the relevant and irrelevant cues. Letters were randomly chosen from a set of M, R, S, X, B, G, H, and K. As shapes we used triangle, diamond, pentagon, star, heart, cross, rhomboid, and an L-shaped figure. Letters and geometric figures were shown on a rectangular white background and had the same size of 2 × 2cm as the colored squares. All stimuli had an eccentricity of 9.46

degrees of visual angle (dva), and had the same probability of occurring either above or below fixation (relevant and irrelevant cues), or to the left or to the right (context and control stimulus).

**Procedure.** After participants gave written consent to the experiment, written instructions were presented that exemplified the events and task demands that occurred within a trial. Eight practice trials were run prior to the actual experiment to assure that participants had understood the instructions.

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Figure 1 about here

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Figure 1 depicts the sequence of events in a trial. The trial started with a fixation cross for 2000ms that was followed by a 4000ms presentation of cues (letter and shape) together with the context and control stimulus (colors). Participants were instructed to inspect the four stimuli and eye movements were recorded to obtain measures of overt attention. Participants had to learn after which combinations of cues they had to press the mouse button once (R1) and after which combinations a double-click (R2) was required. They were instructed to withhold their response until the occurrence of a black circular prompt stimulus. When the black circle occurred, each subsequent mouse click was registered by the occurrence of a white circle within the black circle. The time window to successfully register a response was restricted to 2000ms. After the time window of 2000ms, the black circle disappeared and a feedback screen was presented for 3000ms. Feedback specified the correct response (single-/double-click) by showing one or two white circles within the black circle and again presented the previous set of stimuli. A blank screen was then shown for a random interval of 2000 to 4000ms until the next trial began.

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Table 1 about here

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During the entire experiment the color of one box on the horizontal meridian was the same in all trials. The other colored box provided the context that participants had to encode in order to solve the discrimination. The position of the two colors (left or right of fixation) randomly changed across trials. The critical feature of the trained discrimination was that the context color determined which dimension (letter or shape) was relevant and which was irrelevant for predicting the correct response.

Table 1 depicts the trial types in the current experiment. In Context 1, Cues A1 and A2, which belonged to Dimension A, were reliable predictors of a single and double mouse click respectively, while after B1 and B2, which belonged to Dimension B, both responses were correct with the same probability. This contingency was reversed in Context 2, where Dimension A was irrelevant while Dimension B was predictive of a correct response. Each context was in effect for a block of 16 trials with four replications of each trial type. The two contexts alternated over the first six blocks (three blocks each) yielding a total number of 96 trials in the first stage. In the second stage new elements of Dimensions A and B again were trained in Context 1, A3B3→R1 and A4B4→R2, and in Context 2, A5B5→R1 and A6B6→R2. However, the discriminations now were *optional* because the correct prediction could be made by attending to either Dimension A or to Dimension B in all trials regardless of context.

In both stages of training, we used different pseudo-random trial sequences for each participant.  Trials were randomly shuffled within blocks with the restricting that the same correct response and the same cue did occur a maximum number of three times in a row. The assignment of dimensions letters and shapes to Dimensions A and B was counterbalanced across participants, as was the assignment of specific letters and specific shapes to cues 1 to 6 within these dimensions.

**Data Analysis.** Fixations were detected using a velocity-based algorithm with a threshold of 30°/sec. *Fixation probability* was computed from the frequency of fixating a stimulus element at least once during the 4-sec interval of cue and context presentation. *Fixation dwell time* was computed as the summed duration of all fixations on a stimulus element that occurred in the same interval. Repeated measures analysis of variance (ANOVA) was used to analyze the data. For this and the subsequent experiments, the .05 level of significance was employed for all statistical tests, stated probability levels were based on the Greenhouse-Geisser (1959) adjustment of degrees of freedom where appropriate, and effect sizes were computed as generalized eta squared (Bakeman, 2005). For a focused test of our hypotheses of "more attention to relevant cues and contexts", we used contrast analysis. In the case of multiple testing, p-values were adjusted according to Benjamini and Hochberg (1995) as stated in the results section

**Results and Discussion**

**Predictive learning.** During training, participants learned to anticipate the correct response in 76% of all trials in the acquisition stage (*SEM* = 2.724). This level of correct responding was significantly greater than chance level, $t(25) = 9.430$, $p < .001$. However, closer inspection of performance by individual participants revealed, that the percentage of correct responding followed a clear bimodal distribution as shown in Figure 2.

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Figure 2 about here

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One subgroup of participants succeeded to predict the correct response in a high percentage of trials, while a second subgroup was considerably less accurate. From the empirical distribution of performance we derived a post-hoc factor group that encoded the distinction between poor learners (< 75% correct, $n = 13$) and good learners (> 75% correct, $n = 13$). The probability of a correct response in both groups is shown in Figure 3.

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Figure 3 about here

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For the training stage (left panel), a 2 × 2 ANOVA revealed significant main effects of group, $F(1,24) = 145.95$, $p < .001$, $\eta^2 = .70$, and context, $F(1,24) = 24.68$, $p < .001$, $\eta^2 = .39$, that were modulated by a Group × Context interaction, $F(1,24) = 6.70$, $p = .02$, $\eta^2 = .15$. While good learners performance was slightly better in Context 1 than in Context 2, $t(12) = 2.194$, $p = .049$, the probability of correct responding clearly was above chance level in both contexts (both *p*s < .001 for difference from 0.5). Poor learners on the other hand were characterized by a marked performance difference between contexts, $t(12)=4.497$, $p < .001$. Correct responding in Context 1 was well above chance level, $t(12)=7.285$, $p < .001$, but there was no evidence that correct responding was above chance in Context 2, $t(12)=1.196$, $p = .127$. In the test stage good learners again performed better than poor learners, $F(1,24) = 9.02$, $p = .006$, $\eta^2 = .25$, but differences between contexts were not evident, $F < 1$, and performance was above chance level for both groups in both contexts (all *p*s <. 001).

The difference in context-modulated performance between training and test for poor learners is readily explained by the major difference between the trained discriminations. While in the training stage encoding of the context stimulus was essential for correct responding in both contexts, the context could have been completely ignored in the test stage. For example, if poor learners ignored the context from the very beginning of the training stage they would have failed to detect the context changes and in turn would have failed to disengage attention from Dimension A when it became irrelevant in Context 2. Furthermore, performance in Context 2 would have been restored in the test stage when the correct prediction was possible with attention to either dimension in both contexts. Our analysis of eye movements as a measure of overt attention in the following section will shed further light on this attentional interpretation.

**Attentional learning.** The stimulus display consisting of one letter, one shape (cue elements), and two colored squares (context and control stimulus) was shown for 4 seconds in each trial and participants moved their eyes to focus on some elements at the cost of neglecting other elements. We analyzed fixation probability and fixation dwell time to examine how associative learning affected measures of overt attention.

Figure 4 presents summed fixation dwell times on cue dimension A versus B dependent on the learning context (1 vs. 2). The four different panels depict attentional allocation for the group of good learners (top) and poor learners (bottom) during training (left) and test (right). A super-ordinate ANOVA with factors group (Poor, Good), stage (Train, Test), context (1, 2) and dimension (A, B) revealed significant two-way interactions Group × Dimension, $F(1,24) = 7.065$, $p = .014$, $\eta^2 = .011$, and Dimension × Context, $F(1,24) = 8.444$, $p = .031$, $\eta^2 = .008$, that were further modulated by the three-way interaction Group × Dimension × Context, $F(1,24) = 6.058$, $p = .021$, $\eta^2 = .022$. To further elucidate this interaction, we conducted a planned comparison of cell means using contrast analysis. For the ordering of factor levels shown on the x-axes in Figure 4 the contrast weights $\lambda = [1, -1, -1, 1]$ coded for the joint hypothesis that (a) during training participants paid more attention to the dimension that was relevant in the given context, and (b) this context-dependent attention bias transferred to the test stage. Collapsed across both stages, the contrast was highly significant in the group of good learners, $t(24) = 3.795$, $p < .001$, $r = .612$, where dwell time on relevant cues exceeded dwell time on irrelevant cues. In contrast, the same comparison of cell means was not significant in poor learners, $t(24) = 0.314$, $p < .378$, $r = .064$. For further analysis we tested the contrast for each combination of Group × Stage, where p-values were adjusted for multiple testing (Benjamini & Hochberg, 1995). For good learners the hypothesized contrast was significant for both, the training stage, $t(31) = 3.480$, $p = .002$, $r = .530$, as well as the test stage, $t(31) = 3.606$, $p = .002$, $r = .544$, suggesting that good learners paid more attention to the previously relevant stimulus dimension even if this bias was no longer necessary for solving the task in Stage 2. In comparison, for poor learners, the contrast was neither significant during training, $t(31) = -0.509$, $p = .692$, $r = .091$, nor during test. $t(31) = 1.096$, $p = .187$, $r = .193$ (p-values adjusted for multiple testing of four contrasts).

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Figure 4 about here

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To further explore the actual dwell times observed in the group of poor learners, we conducted separate ANOVAs for both experimental stages. For the training stage this analysis revealed a main effect of dimension, $F(1,12) = 6.442$, $p = .026$, $\eta^2 = .072$, no main effect of context, $F < 1$, and no significant interaction, $F(1,12) = 1.1354$, $p = .307$, $\eta^2 = .003$, indicating that poor learners spent more time fixating on Dimension A, regardless of contexts. The same analysis for the test stage, revealed no main effects of either dimension, $F(1,12) = 2.028$, $p = .179$, $\eta^2 = .003$, or context, $F < 1$, and no interaction $F(1,12) = 3.412$, $p = .089$, $\eta^2 = .012$.

In summary, the analysis of total dwell in the training stage revealed that good learners managed to use the context to focus on the relevant dimension, and switched their attentional focus when the context changed. Poor learners on the other hand acquired an attentional bias for Dimension A that was relevant in the first block of training, but had difficulties disengaging from Dimension A when it became irrelevant in Context 2. This difference in the contextual modulation of attention provides a ready explanation for our findings on predictive learning reported in the previous section: Good learners were able to acquire the correct predictive response in both contexts because they learned to focus on the relevant dimension in each context. Poor learners on the other hand exhibited a selective retardation of correct predictive responding in Context 2 because they failed to disengage from Dimension A and thus focused on cues that were not predictive for the correct response in the second context.

While encoding of the context was essential for predictive learning in the acquisition stage, it was arbitrary in the test stage. The discrimination of A3B3→R1, A4B4→R2 in Context 1 and A5B5→R1, A6B6→R2 in Context 2 could have been acquired successfully without any encoding of the contexts and with a random bias for either Dimension A or B or both in any context. The second stage of our experiment thus provided a test for the hypothesis that the context-dependent attentional bias acquired during associative learning transferred to a learning situation where this bias was not necessary for correct responding. The results suggest that good learners exhibited a perfect transfer: In Context 1 they spent more time fixating on elements of Dimension A than Dimension B, while in Context 2 fixation dwell times were longer for Dimension B than for Dimension A. In contrast, such an effect was absent for poor learners in the test stage.

Besides the two cues (shape, letter) that were presented in each trial, the display also featured the two color stimuli as shown in Figure 1. One color was the context color that specified the relevant cues as either letter or shape, and the other color was a constant control stimulus. Figure 5 depicts the probability of fixating these colors (context vs. control) at least once per trial depending on the color of the context (1 vs. 2) for good learners (top) and poor learners (bottom) during training (left) and test (right). The first aspect to note in Figure 5 is the overall low fixation frequency. On average, participants moved their eyes to fixate the peripheral colored boxes on only about 46% of all trials in the training stage and 40% of all trials in the test stage.

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Figure 5 about here

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Because in the training stage encoding of the context color was essential for correct responding, and good learners exhibited a high percentage of correct responses as shown in Figure 3, it seems as if the context could have been encoded without looking at it directly but rather identifying its color in the visual periphery. Furthermore, with the blocked context changes used in our experiment, participants were likely to realize, that after a context change, the context would be constant for the next series of trials. From this perspective, there just was no need to attend to the context on each and every trial. However, on top of this rather low general fixation frequency, Figure 5 depicts differences between experimental conditions. A super-ordinate ANOVA Group (Poor, Good) × Stage (Train, Test) × Color (Context, Control) × Context (1, 2) revealed a main effect of stage, $F(1,24) = 6.560$, $p = .017$, $\eta^2 = .022$, and a main effect of color, $F(1,24) = 4.787$, $p = .038$, $\eta^2 = .003$, that was modulated by interactions Group × Color, $F(1,24) = 5.416$, $p = .028$, $\eta^2 = .004$, and Group × Color × Context, $F(1,24) = 4.272$, $p = .049$, $\eta^2 = .001$. To further examine this interaction, we conducted a planned comparison of cell means as also reported for fixation dwell time above. For the ordering of factor levels shown on the x-axes in Figure 5 the contrast weights $\lambda = [1, -1, 1, -1]$ coded for the joint hypothesis that (a) during training participants paid more attention to the context color than to the control color, and (b) this attention bias for the context transferred to the test stage. Collapsed across both stages, this contrast was highly significant in the group of good learners, $t(24) = 3.193$, $p = .002$, $r = .545$, where fixation probability for the context color exceeded fixation probability for the control color. In contrast, the same comparison of cell means was not significant in poor learners, $t(24) = -0.099$, $p = .538$, $r = .020$. Further analysis revealed that for good learners the contrast was significant for both, the training stage, $t(44) = 2.268$, $p = .028$, $r = .323$, as well as the test stage, $t(44) = 2.835$, $p = .013$, $r = .391$, suggesting that good learners paid more attention to the previously relevant learning context even if this bias was no longer necessary for solving the task in Stage 2. In comparison, for poor learners, the contrast was neither significant during training, $t(44) = -0.347$, $p = .634$, $r = .052$, nor during test. $t(44) = 0.189$, $p = .567$, $r = .029$ (p-values adjusted for multiple testing of four contrasts).

In summary, the analysis of fixation frequency revealed that good learners exhibited an attentional bias for the context color over the control color that was not evident in poor learners. For good learners, the peripheral color that indicated which cue element (letter or shape) was a good predictor of the outcome attracted gaze with higher probability than the non-informative control color and this attentional bias transferred to the test stage.

The results from Experiment 1 clearly support the conclusion drawn from the studies by Uengoer et al. (2013) and George and Kruschke (2012) that attention can come under the control of contextual stimuli. Participants who successfully mastered a conditional discrimination for which cues from Dimension A were relevant in Context 1, but irrelevant in Context 2, while cues from Dimension B were irrelevant in Context 1, but relevant in Context 2, showed different patterns of overt attention across the contexts during training. More precisely, cues from Dimension A received more overt attention than those from Dimension B in Context 1, while the opposite pattern of overt attention was observed in Context 2. Furthermore, when subsequently presented with novel stimuli from both dimensions possessing equal predictive values, changes in overt attention were transferred to the novel stimuli in a context-specific manner. Thus, although all the novel cues were equally relevant, cues belonging to Dimension A received more overt attention than those from Dimension B when presented in Context 1, while the opposite was observed in Context 2. Moreover, there was no evidence that overt attention was modulated by contextual changes in those participants who failed to successfully solve the initially trained conditional discrimination. This finding confirms that the context-specificity of overt attention observed in the present experiment was related to learning experience and not to other aspects of the procedure.

## Experiment 2

In Experiment 1 and in the studies by Uengoer et al. (2013) and George and Kruschke (2012), context-dependent associability was induced by means of a conditional discrimination in which each cue was explicitly trained as both relevant and irrelevant depending on the context. The second aim of the present study was to investigate whether such explicit training in which the significance of a cue changes according to context is necessary for the formation of contextual control of associability. This question was addressed by Experiments 2 and 3.

Both experiments used a procedure adopted by Uengoer et al. (2013). For each trial, participants were shown two cues from two dimensions (A, B; letter, shape), presented side by side, and the context was provided by a colored rectangular frame surrounding the cues. Table 2 illustrates the design for the two groups of Experiment 2. Initially, all participants received discrimination training across two contexts. In Context 1, outcomes were predictable on the basis of two cues from Dimension A (A1 and A2), while two cues from Dimension B (B1 and B2) were irrelevant. In Context 2, the discrimination involved another set of cues from either dimension (A3, A4, B3, B4) and was solvable on the basis of those belonging to Dimension B, while Dimension A was irrelevant. Hence, the significance of each cue remained unchanged throughout training and the discrimination was solvable on the basis of cues A1, A2, B3 and B4, while the remaining cues or the contexts were, in principle, not required for accurate performance.

In Stage 2, participants were trained with an optional-shift discrimination involving novel cues from both dimensions (A5, B6). In the optional-shift discrimination, compound A5B5 was paired with Outcome O1, and compound A6B6 with O2. Half of the participants (Group C1) received the optional-shift discrimination in Context 1, while the other half (Group C2) was trained in Context 2.

In order to assess the way in which participants solved the optional-shift discrimination from Stage 2, transfer compounds A5B6 and A6B5 were tested in Stage 3 either in Context 1 (Group C1) or in Context 2 (Group C2).

If training of the discrimination in Stage 1 induces context-dependent changes in associability, participants in Group C1 will solve the optional-shift discrimination from Stage 2 on the basis of Dimension A, whereas participants in Group C2 will rely on Dimension B during the second stage. As a consequence, Group C1 will show a higher proportion of Outcome 1-predictions in response to the transfer compound A5B6 than to the compound A6B5, while we should observe the opposite in Group C2 with a higher proportion of Outcome 1-predictions for A6B5 than A5B6. In contrast, if the Stage 1-discrimination is unable to establish context-dependent associability, then there should be no systematic learning bias in favor of one dimension during the subsequent stages in each group. Accordingly, a difference in responding between the two transfer compounds should be observed in neither group.

In order to facilitate acquisition of the initial discrimination for our participants, we simplified our experimental procedure. First, recording of eye-gaze was abandoned, as this measure was not necessary to assess the predictions just described for the transfer stage. In this way, we avoided demands caused by task requirements related to gaze position recording. Second, we included a period of preliminary training in which participants were given the opportunity to acquire the Stage 1-discrimination step by step (for details, see Method section).

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Table 2 about here

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**Method**

**Participants.** A group of 64 students of Philipps-Universität Marburg (of which 45 were females) participated in Experiment 2. Their ages varied between 18 and 35 years, with a median of 23. They either participated in order to meet course requirements or were paid for their attendance. Participants were randomly allocated to the two groups as they arrived at the experimental room. They were tested individually and required approximately 15 min to complete the experiment. For six additional participants, the experiment was terminated during a preliminary training period because they failed to complete one of four phases of this preliminary treatment within 40 trials (see below). Furthermore, data of two additional participants were excluded from analyses because their predictions were incorrect on more than 30 % of the eight trials presented during the first or second half of the last block of Stage 1 (see below). Participants gave informed written consent to participate in the experiment.

**Apparatus and procedure.** Instructions and further necessary information were presented on a computer screen. Participants interacted with the computer using the mouse. Twelve different squares (with a side length of 4 cm each) were used as cues. Each of six of these squares displayed a white line drawing of one of six geometric shapes (circle, cross, parallelogram, pentagon, star, or triangle) on a black background. Each of the remaining squares showed one of six capital letters (G, K, M, P, S, or Y) in black font on a white background. A red and a blue rectangular frame served as Contexts 1 and 2. The frames were 24 cm wide and 12 cm high. The two different outcomes were the numbers 1 (O1) and 2 (O2). For each group, the stimuli were counterbalanced as follows. Half of the participants received the red frame as Context 1 and the blue frame as Context 2, whereas for the other half, the blue frame served as Context 1 and the red frame as Context 2. For half of the participants in each of these two context conditions, Cues A1 to A6 represented the six geometric shapes and Cues B1 to B6 represented the six capital letters. For the other half, Cues A1 to A6 represented the letters and Cues B1 to B6 represented the shapes. Both the assignment of specific shapes or letters to Cues A1 to A6 and the assignment of specific shapes or letters to Cues B1 to B6 were implemented randomly for each participant.

Each participant was initially asked to read the following instructions (in German) on the screen:

"This study is concerned with the question of how people learn about relationships between different events. In the following experiment, you will be shown a succession of different figures. Each figure is composed of two symbols surrounded by a coloured frame. Moreover, each figure belongs to a specific category: Category 1 or Category 2. Your task is to find out which figures belong to Category 1 and which figures belong to Category 2. To solve this task, you will be shown different figures one after the other. For each figure, you should predict whether it belongs to Category 1 or Category 2. For this prediction, there will be two response buttons available. After you have made your prediction, you will be informed about the category membership of the figure. Use this feedback to discover which figures belong to Category 1 and which figures belong to Category 2.

Obviously, at first you will have to guess, as you do not know anything about the criteria for categorization. But eventually you will find out according to which criteria the figures are assigned to the categories. On the basis of this knowledge, you should make correct predictions- as many as possible.

For all of your answers, accuracy rather than speed is essential. Please do not take any notes during the experiment. If you have any more questions please ask them now. If you don't have any questions, please start the experiment by clicking on the *Next* button."

On each trial, two squares displaying one shape and one letter were shown on the top half of the screen. The two squares were presented side by side, with the left–right allocation of shape and letter determined randomly on each trial. Each square appeared at a distance of 4 cm from the vertical centre of the display. Squares were surrounded by a rectangular frame in either red or blue. Participants were asked to predict the category membership of the stimulus configuration by clicking on one of two answer buttons labelled "1" or "2". Immediately after they responded, another window appeared, telling participants the category membership of the stimulus configuration. Participants had to confirm that they had read the feedback by clicking on an "OK" button. Subsequently, the next trial started.

During Stage 1, all participants received discrimination training in two different contexts. In Context 1, Cues A1 and A2 signaled category membership, while Cues B1 and B2 were irrelevant. In Context 2, the task was based on Cues B3 and B4, while Cues A3 and A4 were irrelevant. Stage 1 comprised 80 trials and was divided into five blocks each of 16 trials. Within each block, the four trial types related to the same context were presented on eight consecutive trials with each trial type presented twice in a random order. Whether a block started with trials in Context 1 or Context 2 was determined randomly for each block and each participant, except for the final block of Stage 1. In this case, the order of contexts was counterbalanced across participants.

A period of preliminary training was given prior to Stage 1 in order to facilitate acquisition of the discriminations (e.g. Mitchell, Griffiths, Seetoo, & Lovibond, 2012; Uengoer et al., 2013). There were four phases of this preliminary treatment (Phase Ctx1/a: Context 1: A1→O1, A2→O2; Phase Ctx1/ab: Context 1: A1B1→O1, A1B2→O1, A2B1→O2, A2B2→O2; Phase Ctx2/b: Context 2: B3→O1, B4→O2; Phase Ctx2/ab: Context 2: A3B3→O1, A3B4→O2, A4B3→O1, A4B4→O2). Each preliminary phase comprised at least one block of eight trials. The number of additional blocks given to a participant depended on their prediction accuracy. Within each block of Phases Ctx1/a and Ctx2/b, each of the two trial types was presented four times in a random order; within each block of Phases Ctx1/ab and Ctx2/ab, each of the four trial types was presented twice in a random order. If participants accomplished one block of a phase without an incorrect prediction, the next phase was initiated. Otherwise, the phase was repeated for a further block. If participants failed to complete one phase within 40 trials (5 blocks), the experiment was terminated. Phase Ctx1/a was always followed by Phase Ctx1/ab and Phase Ctx2/b was always followed by Phase Ctx2/ab. Whether preliminary training commenced in Context 1 or in Context 2 was counterbalanced across participants in each group. Stage 1 started immediately after the completion of the four preliminary phases.

After participants completed Stage 1, they immediately received a discrimination with A5B5→O1 and A6B6→O2 trials. Thus, outcomes during this stage were predictable on the basis of Cues A5 and A6 as well as on the basis of Cues B5 and B6. For half of the participants, this discrimination training was conducted in Context 1 (Group C1), whereas for the other half, training took place in Context 2 (Group C2). Stage 2 comprised five blocks each of four trials. Within each block, each of the two trial types was presented twice in a random order.

Following Stage 2, participants received a series of test trials with A5B5, A5B6, A6B5, and A6B6 either in Context 1 (Group C1) or in Context 2 (Group C2). This test was introduced by the following instructions: "Now the feedback telling you the correct category membership of a figure will be omitted. Nevertheless, please exert yourself to predict which figures belong to Category 1 and which figures belong to Category 2." The setup of the test trials was identical to that of the previous trials, with the exception that the feedback window was omitted. The Test Stage comprised 24 trials and was divided into three blocks each of eight trials. Within each block, each of the four trial types was presented twice in a random order.

**Results and Discussion**

The left-hand panel of Figure 6 presents the mean proportions of correct predictions across the five blocks of Stage 1 separated by group and context. As can be seen, participants showed a high level of accuracy throughout Stage 1 indicating the effectiveness of the preliminary exercise phase. Most importantly, performance during Stage 1 did not differ across groups and contexts.

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Figure 6 about here

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This was confirmed by a 2 × 5 × 2 repeated measures ANOVA on the proportions of correct predictions, including the within-subjects factors context (1 vs. 2) and block (1–5), and the between-subjects factor group (C1 vs. C2). The analysis revealed no main effect of block, $F(4, 248) = 1.59$, $p = .19$, yielding no evidence that the level of accuracy changed in the course of Stage 1-training. The main effects of context and group and all interactions including either or both of these factors were not significant, all *F*s < 1.38, indicating that performance did not differ significantly across contexts and groups.

The right-hand panel of Figure 6 shows the mean proportions of correct predictions across the five blocks of Stage 2 separated by group. A Block (1–5) × Group (C1 vs. C2) ANOVA on the proportions of correct predictions revealed a main effect of block, $F(4, 248) = 51.55$, $p < .001$, $\eta^2 = .364$, indicating that the accuracy of predictions increased across the blocks of Stage 2. Neither the main effect of group nor the Block × Group interaction was significant, both *F*s < 1.84, showing that performance during Stage 2 did not significantly differ between Contexts 1 and 2.

Figure 7 presents the performance of our participants during the Test Stage in which feedbacks about the outcomes were omitted. The data shown are the mean proportion of Outcome 1-predictions across the six presentations of each trial type separated by group.

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Figure 7 about here

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For the compounds that were already trained in Stage 2, A5B5 and A6B6, all participants responded during the Test Stage according to the contingencies that they had experienced in the previous phase. A Cue (A5B5 vs. A6B6) × Group (C1 vs. C2) ANOVA on the proportions of Outcome 1-predictions revealed a main effect of cue, $F(1, 62) = 482.35$, $p < .001$, $\eta^2 = .877$, showing a higher proportion of Outcome 1-predictions to A5B5 than to A6B6. The main effect of group and the Cue × Group interaction were not significant, both *F*s < 1, indicating no evidence for a difference in discrimination performance across the groups.

In case of the transfer compounds A5B6 and A6B5, the two groups showed opposite patterns of discrimination performance during the Test Stage. A Cue (A5B6 vs. A6B5) × Group (C1 vs. C2) ANOVA on the proportions of Outcome 1-predictions revealed neither a main effect of cue nor a main effect of group, both *F*s < 1, but a significant Cue × Group interaction, $F(1, 62) = 17.22$, $p < .001$, $\eta^2 = .212$, indicating that discrimination between the cues varied across groups. We found that participants in Group C1 predicted Outcome 1 with a higher proportion for A5B6 than for A6B5, $t(31) = 2.59$, $p = .015$, while participants in Group C2 showed the opposite pattern with a higher proportion of Outcome 1-predictions for A6B5 than for A5B6, $t(31) = -3.35$, $p = .002$.

Overall, after having acquired a discrimination for which two cues from Dimension A were relevant in Context 1, and two other cues from the same dimension were irrelevant in Context 2, while two cues from Dimension B were irrelevant in Context 1, and two other cues from the dimension were relevant in Context 2, participants solved a second discrimination, for which novel cues from both dimensions were equally relevant, in different ways depending on the context. When the second discrimination was given in Context 1, participants more readily learned about the cues from Dimension A than Dimension B, while in Context 2, learning took place more readily about cues from Dimension B than A. This finding is consistent with the view that the initial training resulted in context-specific changes in associability: in Context 1, the associability of cues from Dimension A was greater than that of cues from Dimension B, whereas in Context 2, cues from Dimension B possessed greater associability than those from Dimension A.

Our finding is inconsistent with a proposal put forward by Uengoer et al. (2013) that context-specific changes in associability may only emerge under conditions in which the significance of a cue changes according to context (see also, George & Kruschke, 2012). To our knowledge, Experiment 2 is the first to provide evidence that changes in associability during discrimination learning can come under the control of contextual stimuli in the absence of associative interference. In order to demonstrate the reliability of our finding, the purpose of Experiment 3 was to provide additional evidence for our conclusion by using another kind of test procedure.

## Experiment 3

The design of Experiment 3 is shown in Table 3. Stage 1 of the experiment was identical to that of Experiment 2. Thus, two groups of participants were initially trained with a discrimination involving two contexts; two cues from Dimension A were relevant in Context 1, while another pair of cues from this dimension was irrelevant in Context 2, and two cues belonging to Dimension B were irrelevant in Context 1, while another pair of cues from this dimension was relevant in Context 2. In Stage 2, participants received a discrimination composed of novel cues from either dimension for which Dimension A was relevant and Dimension B was irrelevant. For half of the participants (Group C1), the discrimination in Stage 2 was conducted in Context 1, whereas for the other half (Group C2), training in Stage 2 took place in Context 2. If, as concluded from the previous experiment, the original training results in context-dependent changes in associability, then during Stage 2, the irrelevant Dimension B will initially possess greater associability than the relevant Dimension A in Group C2, which should impair acquisition of the discrimination compared to Group C1 in which the relevant dimension should have greater associability than the irrelevant dimension from the outset of Stage 2.

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Table 3 about here

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### Method

**Participants**. Another group of 64 students of Philipps-Universität Marburg (of which 39 were females) participated in Experiment 3. Their ages varied between 20 and 53 years, with a median of 23. Participants either attended in order to meet course requirements or were paid with sweets. They were randomly allocated to the two groups as they arrived at the experimental room and were tested individually. Participants required approximately 15 min to complete the experiment. For four additional participants, the experiment was terminated during a preliminary training period because they failed to complete one of four phases of this preliminary treatment within 40 trials. Furthermore, data of one additional participant was excluded from analyses because the predictions were incorrect on more than 30 % of the eight trials presented during the first or second half of the last block of Stage 1. All participants gave informed written consent to participate in the experiment.

**Apparatus and procedure**. The instructions, stimuli, and procedure were identical to those aspects of Experiment 2, unless stated otherwise. Following Stage 1, all participants immediately received a discrimination based on Cues A5 and A6, while Cues B5 and B6 were irrelevant. For half of the participants, this discrimination training was conducted in Context 1 (Group C1), whereas for the other half, training took place in Context 2 (Group C2). Stage 2 comprised five blocks each of eight trials. Within each block, each of the four trial types was presented twice in a random order.

## Results and Discussion

The left-hand panel of Figure 8 presents the mean proportions of correct predictions across the five blocks of Stage 1, separated by group and context. A Context (1 vs. 2) × Block (1–5) × Group (C1 vs. C2) ANOVA revealed a main effect of block, $F(4, 248) = 4.70$, $p$ = 003, $\eta^2 = .021$. All other main effects or interactions were not significant, *F*s < 1.72.

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Figure 8 about here

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The right-hand panel Figure 8 presents the mean proportions of correct predictions across the five blocks of Stage 2 for each group. A Block (1–5) × Group (C1 vs. C2) ANOVA revealed a main effect of block, $F(4, 248) = 42.16$, $p < .001$, $\eta^2 = .269$, and a main effect of group, $F(1, 62) = 4.07$, $p = .048$, $\eta^2 = .029$, reflecting that the accuracy of predictions was higher in Group C1 than in Group C2. The Block × Group interaction was not significant, $F(4, 248) = 1.28$, $p = .29$.

After a discrimination for which cues from Dimension A and Dimension B were trained as relevant and irrelevant, respectively, in Context 1, while other cues from Dimension A and Dimension B were irrelevant and relevant, respectively, in Context 2, a second discrimination, for which novel cues from Dimension A were relevant and novel cues from Dimension B were irrelevant, was acquired more rapidly when it was conducted in Context 1 compared to training in Context 2. Consistent with the previous experiment, the results from Experiment 3 support the conclusion that changes in associability during discrimination learning can come under the control of context, even under conditions in which contextual information is not essential for successful acquisition.

## General Discussion

In each of three experiments, we found evidence that attention can be modulated by context. In the initial phase of each experiment, participants received a discrimination for which cues from Dimension A were relevant in Context 1, but irrelevant in Context 2, while cues from Dimension B were irrelevant in Context 1, but relevant in Context 2. Experiment 1 used the same set of cues in Contexts 1 and 2, while in Experiments 2 and 3, different cues were presented across the contexts. Following initial training, participants in each experiment were trained with a transfer discrimination involving novel cues from both dimensions. In Experiments 1 and 2, the transfer discrimination was optional as it was solvable on the basis of either Dimension A or B (or both), while for the transfer discrimination in Experiment 3, Dimension A was relevant and Dimension B was irrelevant.

In Experiment 1, measures of eye-gaze showed that Dimension A received more overt attention than Dimension B when the transfer task was given in Context 1, while the opposite pattern of overt attention was found in Context 2. Results from the transfer discrimination in

Experiment 2 revealed that the discrimination was solved on the basis of Dimension A when trained in Context 1, but on the basis of Dimension B in Context 2. In Experiment 3, we observed that the transfer discrimination was acquired more rapidly when given in Context 1 compared to Context 2.

The finding that attention can be brought under contextual control had been documented in previous studies by Uengoer et al. (2013) and George and Kruschke (2012). The present experiments go beyond these previous studies in two important ways. First, by recording eye-gaze as a marker of attention, Experiment 1 provided converging evidence for context-specific attention, which is strong support for the validity of the conclusions drawn from the studies by Uengoer et al. and George and Kruschke. Second, Experiments 2 and 3 demonstrated contextual control of stimulus associability despite the absence of associative interference on the level of individual cues.

The results from Experiments 2 and 3 indicate that associative interference is not a necessary condition for the formation of context modulated attention, contrary to proposals put forward by Uengoer et al. (2013) and George and Kruschke (2012) in order to reconcile their findings with those reported by Griffiths and Le Pelley (2009), who found no evidence that associability is influenced by contextual changes. However, the present Experiments 2 and 3 featured another source of interference – context-dependent alternations in the significance of entire stimulus dimensions. Such a source of interference was absent in the study by Griffiths and Le Pelley, which may be an important procedural difference that is responsible for the diverging results. For example, during training of the initial discriminations in Experiments 2 and 3, participants may have, at first, transferred changes in attention that were encouraged by training in one context to the different cues trained in the other context. Such transfer of attentional changes from one context to the other would be detrimental for accurate performance during the first experimental stage, which may have encouraged the formation of contextual control of attention to overcome this source of interference.

The present study is challenging for many theories of learning and attention (e.g., Kruschke, 1992; Le Pelley, 2004; Mackintosh, 1975; Pearce et al., 1998; Pearce & Mackintosh, 2010). Our results are in keeping with the general principle adopted by these models that relevant cues receive more attention than irrelevant stimuli, and that these differences in attention influence the ease with which learning about the stimuli takes place. However, these theories characterize attention to a stimulus in a context-independent manner, and are, therefore, unable to deal with the present results indicating that attention can come under contextual control. In the following paragraphs, we present two of these theories in more detail - the theory of attention by Mackintosh (1975) and Kruschke's (1992) ALCOVE.

Mackintosh (1975) proposed that attention to a stimulus will increase if an outcome is predicted more accurately on the basis of this stimulus than on the basis of all other stimuli concurrently present, whereas attention to a stimulus will decrease if an outcome is predicted more accurately by other accompanying stimuli. Mackintosh assumed that changes in both associative strength and attention occur to individual cues. The model adopts an elemental view of stimulus representation in which specific combinations of stimuli are not encoded. Thus, successful acquisition of the conditional discrimination from Experiment 1 lies outside the scope of the model. Therefore, our first experiment may be considered as not appropriate for assessing the theory. However, acquisition of the initial discrimination from Experiments 2 and 3 poses no challenge for Mackintosh's theory as it is solvable on the basis of four individual cues (A1, A2, B3, B4). According to the model, training of the discrimination will result in considerable attention to the four relevant cues, whereas the remaining cues and the contexts will undergo decreases in attention, which makes it impossible for the model to account for the differences in learning during the transfer discrimination observed in each of the Experiments 2 and 3.

Kruschke’s (1992) ALCOVE can deal with each of the initial discriminations in the present study. This configural model assumes a stimulus representation that characterizes stimuli as points in a multidimensional psychological space. The input layer consists of nodes, each corresponding to a single psychological dimension, and is connected to a hidden layer of nodes representing training exemplars. Activation of hidden nodes depends on the similarity between the exemplar represented by a node and the external stimulus. The functional role of attention in this model is to increase or decrease the importance of individual dimensions for the calculation of the similarity between an exemplar and a stimulus. For each of the present experiments, ALCOVE predicts that training of the initial discrimination will result in Dimension A, Dimension B, and the contexts receiving the same amount of (high) attention. Thus, the model is also unable to anticipate the context-specific changes in attention indicated by the results from each of the present experiments.

The assumption that attention to a stimulus may vary according to the context in which it appears was put forward by Sutherland and Mackintosh (1971) and a formal versions of this idea can be found, for instance, in Kruschke’s (2001) EXIT model. In the model, attention to a stimulus is mediated by exemplar nodes encoding specific stimulus configurations. Thus, in the model, it is possible that a stimulus receives different amounts of attention depending on other accompanying stimuli. However, in its current form, EXIT does not provide an entirely satisfying account for the present results. For the process of learning stimulus-outcome associations, the model adopts a purely elemental view of stimulus representation, which makes it impossible for the model to account for the acquisition of the conditional discrimination from Experiment 1. And, the model assumes that changes in attention occur on the level of individual cues. Changes in attention may generalize to other similar cues, but the rules governing generalization of attention are not specified. Therefore, it remains unclear whether the model is able to account for the results from the transfer stages of the present experiments.

The present study is consistent with the general assumption that more attention is paid to stimuli that reliably signal upcoming events than to unreliable signals. A different relationship between prediction value and attention was proposed by Pearce and Hall (1980). They suggested that stimuli that are followed by unexpected events receive more attention in order to facilitate further learning about these stimuli. The present results are not in accordance with this proposition, but, for other learning situations, it was found that changes in attention follow the principles advocated by Pearce and Hall (e.g., Hogarth, Dickinson, Austin, Brown, & Duka, 2008; Kaye & Pearce, 1984). Future research may investigate whether changes in attention according to Pearce and Hall can also come under the control of contextual stimuli.

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**Tables**

Table 1

*Design of Experiment 1*

| Stage | Block | Context | Discrimination |
|---|---|---|---|
| 1 | 1, 3, 5 | C1 | **A1**B1→R1, **A1**B2→R1<br>**A2**B1→R2, **A2**B2→R2 |
| | 2, 4, 6 | C2 | A1**B1**→R1, A1**B2**→R2<br>A2**B1**→R1, A2**B2**→R2 |
| 2 | 7, 9 | C1 | **A3B3**→R1, **A4B4**→R2 |
| | 8, 10 | C2 | **A5B5**→R1, **A6B6**→R2 |

*Note.* Contexts C1 and C2 are squares in different colors. A and B refer to stimulus dimensions shapes and letters (counterbalanced) and related indices assign specific values of a dimension. R1 and R2 are different responses (single and double mouse click). Relevant cues are shown in bold.

Table 2

*Design of Experiment 2*

| Stage | Context | Group C1 | Group C2 |
|---|---|---|---|
| 1 | C1 | **A1**B1→O1, **A1**B2→O1<br>**A2**B1→O2, **A2**B2→O2 | **A1**B1→O1, **A1**B2→O1<br>**A2**B1→O2, **A2**B2→O2 |
| | C2 | A3**B3**→O1, A3**B4**→O2<br>A4**B3**→O1, A4**B4**→O2 | A3**B3**→O1, A3**B4**→O2<br>A4**B3**→O1, A4**B4**→O2 |
| 2 | C1 | **A5B5**→O1, **A6B6**→O2 | |
| | C2 | | **A5B5**→O1, **A6B6**→O2 |
| 3 | C1 | A5B5→?, A5B6→?<br>A6B5→?, A6B6→? | |
| | C2 | | A5B5→?, A5B6→?<br>A6B5→?, A6B6→? |

*Note.* Contexts C1 and C2 are rectangular frames in different colors. A and B refer to stimulus dimensions shapes and letters (counterbalanced) and related indices assign specific values of a dimension. O1 and O2 are different categories. “?” represents absence of feedback to participants. Relevant cues are shown in bold.

Table 3

*Design of Experiment 3*

| Stage | Context | Group C1 | Group C2 |
|---|---|---|---|
| 1 | C1 | **A1**B1→O1, **A1**B2→O1<br>**A2**B1→O2, **A2**B2→O2 | **A1**B1→O1, **A1**B2→O1<br>**A2**B1→O2, **A2**B2→O2 |
| | C2 | A3**B3**→O1, A3**B4**→O2<br>A4**B3**→O1, A4**B4**→O2 | A3**B3**→O1, A3**B4**→O2<br>A4**B3**→O1, A4**B4**→O2 |
| 2 | C1 | **A5**B5→O1, **A5**B6→O1<br>**A6**B5→O2, **A6**B6→O2 | |
| | C2 | | **A5**B5→O1, **A5**B6→O1<br>**A6**B5→O2, **A6**B6→O2 |

*Note.* Contexts C1 and C2 are rectangular frames in different colors. A and B refer to stimulus dimensions shapes and letters (counterbalanced) and related indices assign specific values of a dimension. O1 and O2 are different categories. Relevant cues are shown in bold.

**Figures**

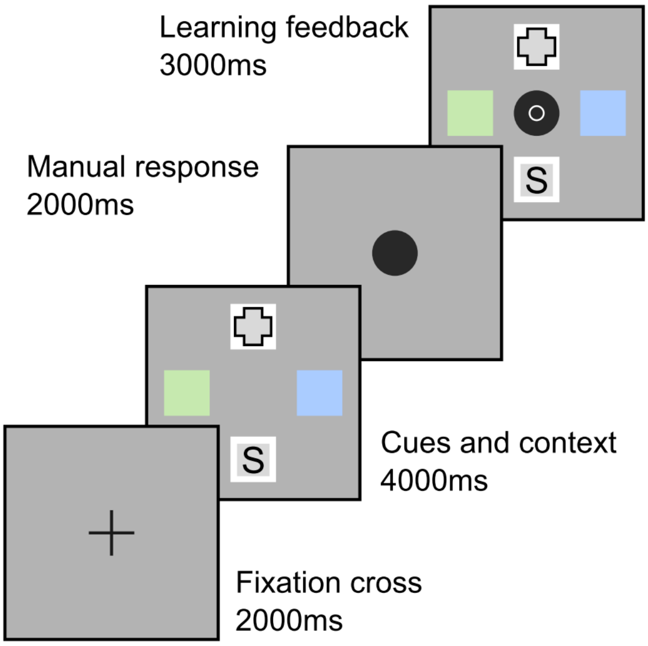


**Figure 1.** Sequence of events in a trial of Experiment 1.

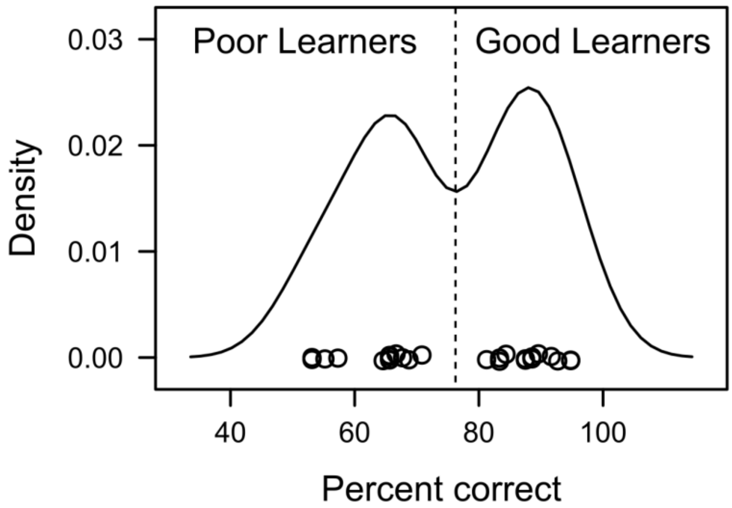


**Figure 2.** Bimodal distribution of the individual levels of correct responding in the acquisition phase of Experiment 1. Learners were classified as “poor” versus ”good” based on a cutoff value of 75%. Note that a score higher than 75% means that good learners responded above chance level (50%) in *both* learning contexts of the acquisition phase, whereas a score smaller or equal to 75% could have been caused by the acquisition of correct responding in one context only.

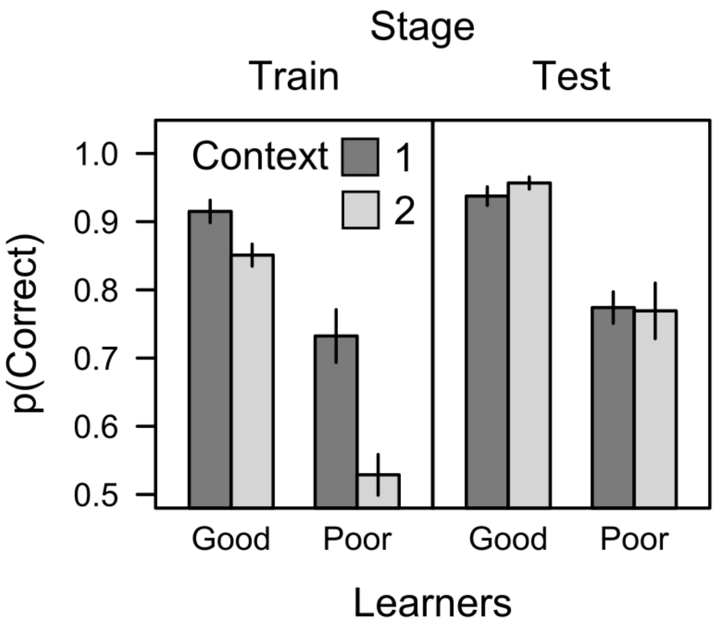


**Figure 3.** Probability of a correct response dependent on post-hoc factor group (Good Learners, Poor Learners), stage (Training, Test) and context (1, 2) in Experiment 1. In the training stage poor learners specifically failed to acquire correct responses in the second context. Error bars denote standard error of the means.

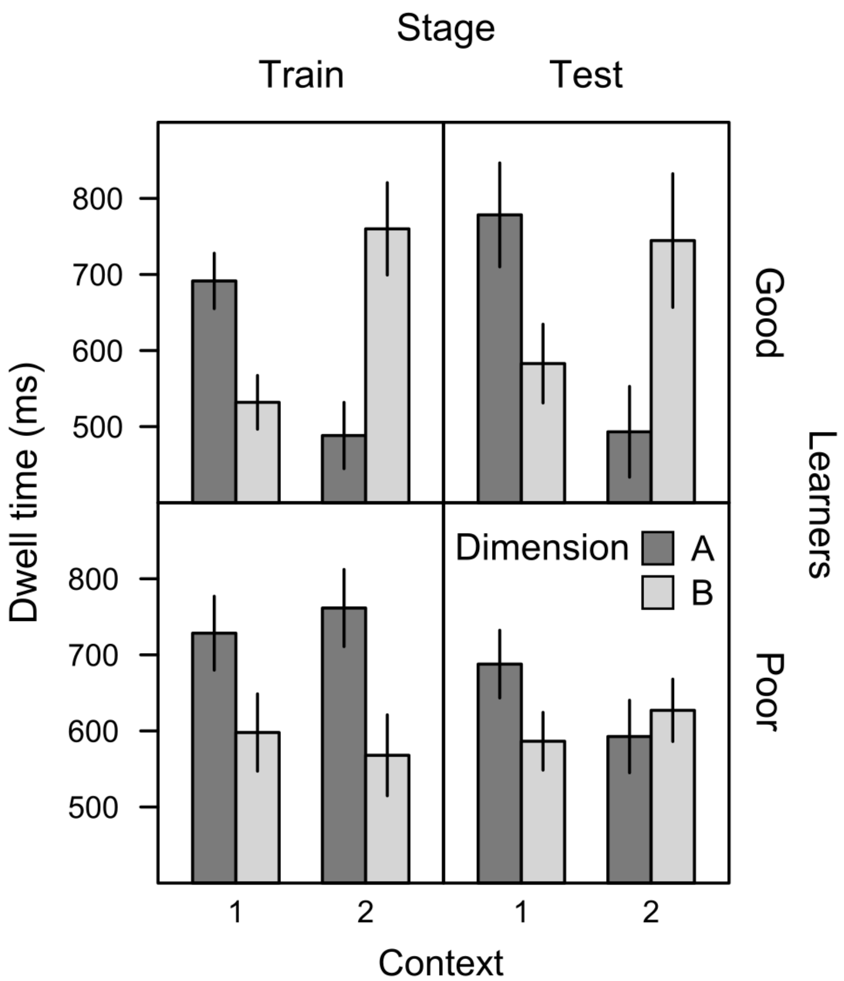


**Figure 4.** Fixation dwell time on cue dimensions in Experiment 1. Error bars denote standard error of the means.

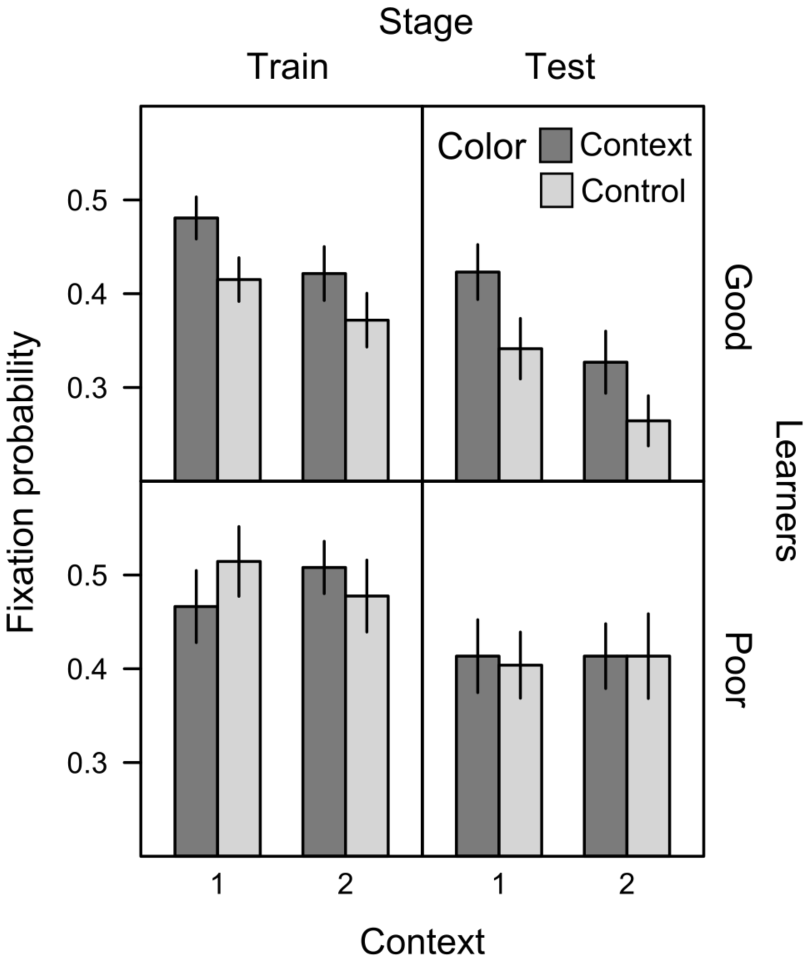


**Figure 5.** Probability of fixating the colored context and control stimulus during the 4-sec interval of presentation in Experiment 1. Error bars denote standard error of the means.

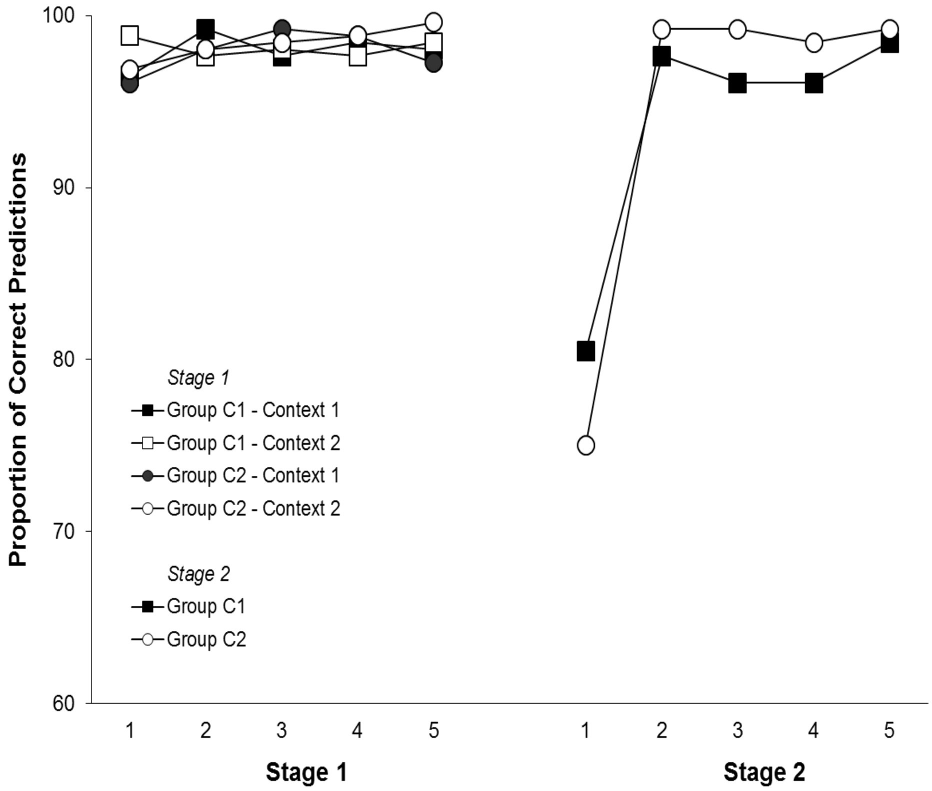


**Figure 6.** Mean proportions of correct predictions across the five blocks of Stage 1 (left panel) and the five blocks of Stage 2 (right panel) of Experiment 2 separated by groups and contexts.

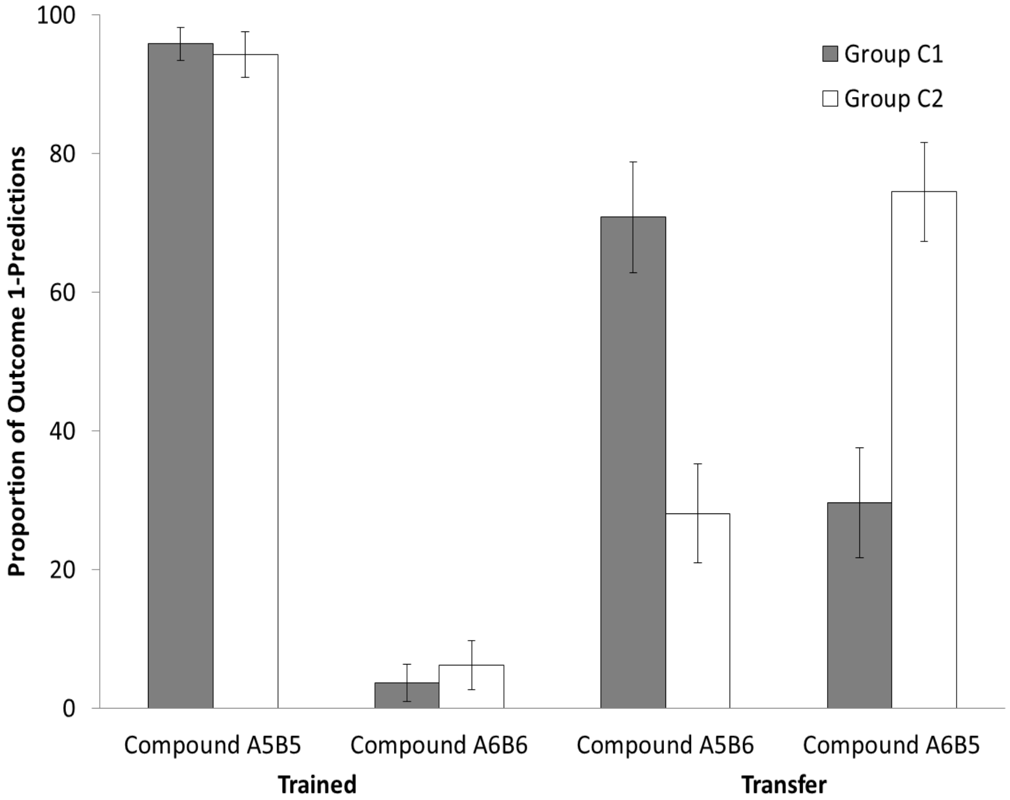


**Figure 7.** Mean proportions of Outcome 1-predictions across the four trial types presented during Stage 3 of Experiment 2, collapsed across the six presentations of each trial type within each group. Error bars denote standard error of the means.

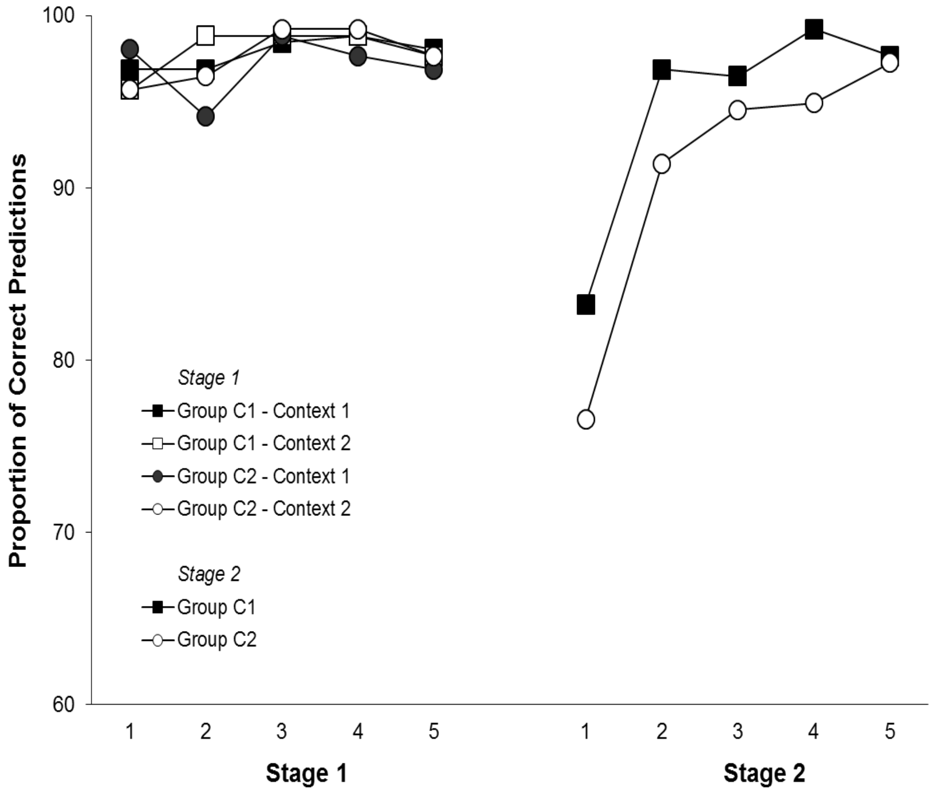


**Figure 8.** Mean proportions of correct predictions across the five blocks of Stage 1 (left panel) and the five blocks of Stage 2 (right panel) of Experiment 3 separated by groups and contexts.