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Attention toward contexts modulates context-specificity of behavior in human predictive learning: Evidence from the *n*-back task

Metin Uengoer[1] · Sara Lucke[1] · Harald Lachnit[1]

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Abstract
According to the attentional theory of context processing (ATCP), learning becomes context specific when acquired under conditions that promote attention toward contextual stimuli regardless of whether attention deployment is guided by learning experience or by other factors unrelated to learning. In one experiment with humans, we investigated whether performance in a predictive learning task can be brought under contextual control by means of a secondary task that was unrelated to predictive learning, but supposed to modulate participants' attention toward contexts. Initially, participants acquired cue-outcome relationships presented in contexts that were each composed of two elements from two dimensions. Acquisition training in the predictive learning task was combined with a one-back task that required participants to match across consecutive trials context elements belonging to one of the two dimensions. During a subsequent test, we observed that acquisition behavior in the predictive learning task was disrupted by changing the acquisition context along the dimension that was relevant for the one-back task, while there was no evidence for context specificity of predictive learning when the acquisition context was changed along the dimension that was irrelevant for the one-back task. Our results support the generality of the principles advocated by ATCP.

Keywords Human learning · Acquisition · Context · Attention · *N*-back task

Does learning taking place in one situation completely transfer to other situations, or is learning to some extent specific to the context of acquisition? According to the attentional theory of context processing (ATCP; Rosas, Callejas-Aguilera, Ramos-Álvarez, & Abdad, 2006), the answer to this question depends on features of the learning situation determining attention deployment. A core assumption of ATCP is that if an organism pays attention to the context, then any information learned in this context is processed in a way that renders it context specific. ATCP specifies several factors that influence the amount of attention toward contextual stimuli. These factors can be divided in two classes. One class of factors considers that attention toward contexts is modulated by learning experience. This class comprises the factors experience with contexts, informative value of contexts, and presence of ambiguous information, each of these factors being consistent with principles advocated by formal theories of learning and attention (e.g., Mackintosh, 1975; Pearce & Hall, 1980).

ATCP (Rosas et al., 2006) assumes that the amount of attention paid to context stimuli changes with context experience. With this proposal, ATCP takes account of findings indicating that contextual control of acquisition diminishes over the course of training in an incidental context (e.g., Hall & Honey, 1990; León, Abad, & Rosas, 2010a, 2011; but see Bonardi, Honey, & Hall, 1990). According to ATCP, incidental context stimuli may receive considerable attention early in learning, but this attention decreases with progressive training as the inferiority of the context's predictive value becomes evident (see Mackintosh, 1975; for support from eye tracking, see Aristizabal, Ramos-Álvarez, Callejas-Aguilera, & Rosas, 2016).

ATCP (Rosas et al., 2006) also proposes that the informative value of contexts affects attention deployment. This assumption is based on results showing that acquisition is more context specific when training was conducted in a context that provides information about cue-outcome contingencies than in an uninformative context (e.g., León, Abad, & Rosas, 2010b; Lucke, Lachnit, Koenig, & Uengoer, 2013; Preston, Dickinson, & Mackintosh, 1986). To account for this finding, ATCP assumes that contexts with predictive value receive

✉ Metin Uengoer
uengoer@uni–marburg.de

[1] Fachbereich Psychologie, Philipps-Universität Marburg, Gutenbergstraße 18, 35032 Marburg, Germany

more attention than those carrying no predictive information (see Mackintosh, 1975; for support from eye tracking, see Lucke et al., 2013, Experiment 2).

Moreover, ATCP (Rosas et al., 2006) assumes that the presence of ambiguous information shifts attention toward context stimuli. With this proposal, ATCP accounts for reports that acquisition performance toward a stimulus is more strongly affected by contextual manipulations when acquisition training took place in a situation in which another stimulus underwent extinction (e.g., Bernal-Gamboa, Rosas, & Callejas-Aguilera, 2014; Rosas & Callejas-Aguilera, 2006, 2007; but see Nelson & Lamoureux, 2015). According to ATCP, the unexpected omission of the outcome in extinction arouses attention toward contextual stimuli (see Darby & Pearce, 1995; Pearce & Hall, 1980).

ATCP (Rosas et al., 2006) also considers that attention to contexts is influenced by a second class of factors that are not based on learning experience. This second class comprises ("nonlearning") factors such as instructions (in case of humans) and the relative salience of contexts and cues.

With ATCP, Rosas et al. (2006) provided an intriguing theoretical framework for understanding the varying impacts of contextual changes on behavior. However, all the empirical evidence supporting ATCP comes from studies aimed at modulating attention to contexts by manipulating subjects' learning history. Empirical research, however, so far widely neglected investigating the impact of "nonlearning" factors on context specificity of behavior.

Therefore, in the present experiment, we investigated whether attention to contextual stimuli modulates context-specificity of acquisition behavior, but in order to manipulate attention toward contexts, we applied a variant of the *n*-back task—a working memory task where performance is unrelated to learning processes. In this kind of task, participants are presented with a sequence of stimuli and are requested to indicate whether the current stimulus matches the stimulus shown *n* trials before. Evidence suggests that working memory load induced by the *n*-back task can reduce processing of task-irrelevant stimuli (e.g., Rose, Schmid, Winzen, Sommer, & Büchel, 2005; Simon, Tusch, Holcomb, & Daffner, 2016).

The current experiment combined a one-back task and a predictive learning task. In the predictive learning task (see Table 1), participants were asked to imagine being a physician whose patient frequently suffers from stomach trouble after meals in restaurants. Participants received a sequence of trials each showing one of several cues (food types) in one of several contexts (restaurants). Each context was composed of two elements: a color spot and a picture of an animal. The context color (Dimension A) was either red or blue (counterbalanced as A1 and A2), and the context animal (Dimension B) was either a bear or a whale (counterbalanced as B1 and B2).

Table 1 The predictive learning schedule of the experiment

Context	Acquisition	Test
A1B1	Z+, F1−	Z?
A1B2	F2+, F3−	Z?
A2B1	F4+, F5−	Z?
A2B2	F6+, F7−	

Note. Context elements A1 and A2 correspond to colored spots (red and blue, counterbalanced), and context elements B1 and B2 to pictures of animals (bear and whale, counterbalanced). Cues Z, F1 to F7 represent pictures of individual food types. "+" = feedback that stomach trouble occurred; "–" = feedback about nonoccurrence of stomach trouble; "?" = participants received no feedback. In addition to the predictive learning regime, participants worked on a one-back task during the acquisition phase, which required matching context elements across consecutive trials. The one-back task was based on A1 and A2 for Group Color, and on B1 and B2 for Group Animal

During the acquisition phase, participants received training with a target cue Z+ in context A1B1. Then, participants received a series of test trials showing cue Z in each of three contexts: (1) the acquisition context A1B1, (2) context A1B2 that differed from the acquisition context only on dimension B, and (3) context A2B1 that differed from the acquisition context only on Dimension A.

During the acquisition phase, participants also performed a one-back task. For half of the participants (Group Color), the one-back task was based on Context Dimension A. For each acquisition trial (except the first one), these participants were asked to indicate whether the context color in the current trial is identical to the context color from the preceding trial. For the other half (Group Animal), the one-back task was based on Context Dimension B. Participants in this group were required to indicate whether the context animal in the current trial is identical to the context animal from the preceding trial.

If performance on the one-back task promotes attention toward the task-relevant stimuli, then participants' attention in Group Color should be biased in favor of context elements from Dimension A, while attention in Group Animal should be biased in favor of context elements from Dimension B. According to ATCP, this difference in attention deployment between the groups should lead to differences in context-specific learning about cue Z: in Group Color acquisition, behavior toward Z should mainly depend on context element A1, while in Group Animal, acquisition should mainly depend on context element B1. As a consequence, changing the acquisition context along Dimension A (context A2B1) during the test phase should disrupt acquisition performance to Z in Group Color, but not in Group Animal. And, changing the acquisition context along Dimension B (context A1B2) should disrupt acquisition performance in Group Animal, but not in Group Color.

Method

Participants

Sixty students from Philipps-Universität Marburg (45 females) participated in the experiment and received either course credit or payment. Their ages varied between 18 and 59 years, with a median of 22. Participants were randomly allocated to the two groups as they arrived at the experimental room. They were tested individually and required approximately 20 minutes to complete the experiment. Participants gave informed written consent to participate in the experiment. The experimental procedure was approved by the ethics committee of the Psychology Department of the Philipps-Universität Marburg.

Apparatus and stimuli

The stimuli, instructions, and further necessary information were presented on a computer screen. Participants interacted with the computer by using the mouse. Pictures of the following food types were used as cues Z, F1 to F7: avocado, banana, broccoli, orange, pear, pepper, pineapple, and strawberry. The assignment of the food types to the cues was implemented randomly for each participant. Four pairs of stimuli served as contexts A1B1, A1B2, A2B1, and A2B2. Each stimulus pair consisted of a color spot (red or blue) and a picture of an animal (bear or whale). Both the assignment of red and blue to context elements A1 and A2 and the assignment of bear and whale to context elements B1 and B2 were implemented randomly for each participant. The two outcomes were the occurrence (+) or nonoccurrence (−) of stomach trouble.

Procedure

Initially, participants received written instructions about the tasks. Participants were asked to imagine being a physician whose patient often suffers from stomach trouble after having eaten certain meals in restaurants, and they were told that their task is to discover the causes of this stomach trouble. Participants were informed that the names of the restaurants visited by the patient were each composed of a color and an animal. Participants were told that they would be shown which restaurant the patient has visited each day and which foods the patient has eaten there. Participants were informed that they would be asked to predict for each day whether the patient suffers from stomach trouble or not, and that each prediction would be followed by feedback about the patient's actual response. Furthermore, participants were instructed to perform a memory task. Half of the participants (Group Color) received the information that they would have to indicate whether the color of the restaurant on a given trial was identical to the restaurant color from the preceding trial, whereas the other half of participants (Group Animal) were told that they would be asked whether the animal of the restaurant on a given trial was identical to the restaurant animal from the preceding trial.

The acquisition phase (see Table 1) comprised 128 trials divided into eight blocks. Each of the eight cue/context combinations (Z+/A1B1, F1−/A1B1, F2+/A1B2, F3−/A1B2, F4+/A2B1, F5−/A2B1, F6+/A2B2, F7−/A2B2) was presented twice per block. The order of presentation was determined randomly for each block and each participant.

On each acquisition trial, two context elements (a color spot and a picture of an animal) were presented side by side on the top half of the screen. The color spot was shown on the left, the picture of the animal on the right. The phrases "The patient ate at the restaurant" and "the following food type" were presented above and below the context elements, respectively. At the center of the screen, a picture of a single food type was shown. Participants were asked to predict whether or not their patient will suffer from stomach trouble after having eaten the food. They made their prediction by clicking on one of two buttons, labeled "Yes, I expect stomach trouble" and "No, I do not expect stomach trouble." Immediately after participants responded, a feedback window appeared, telling whether or not the patient suffered from stomach trouble. By clicking on an "OK" button, the feedback window was replaced by a window showing the one-back question. For half of the participants (Group Color), the one-back question asked whether the color of the restaurant was identical to the restaurant color from the preceding trial, whereas the other half (Group Animal) was asked whether the animal of the restaurant was identical to the restaurant animal from the preceding trial. Participants gave their answer by clicking on one of two buttons labeled "Yes" and "No" and were subsequently informed whether their answer was correct or incorrect. After clicking on an "OK" button, the next trial started (the components of the one-back task were omitted on the first trial of the acquisition phase). The feedback window of the predictive learning task and the components of the one-back task covered the food picture, while the two context elements were displayed throughout a trial.

After completion of the acquisition phase, participants received a series of test trials, which was introduced by instructions informing the participants that both the feedback about the patient's actual reaction and the memory task will be omitted from now on. The test phase consisted of 12 trials. Each of the three cue/context combinations (Z/A1B1, Z/A1B2, Z/A2B1) was presented four times, with the order of presentation randomized for each participant. The test trials were identical to the acquisition trials, except that the feedback on whether or not stomach trouble occurred and the one-back task were omitted.

Results

The .05 level of significance was used in all statistical tests. Stated probability levels were based on the Greenhouse–Geisser (Greenhouse & Geisser, 1959) adjustment of degrees of freedom where appropriate. We used partial eta squared (η_p^2) as the measure of effect size.

The groups equally mastered the one-back task. The mean percentage of correct answers across the 127 one-back trials was 88.42% (*SEM* = 1.14) in Group Color, and 90.11% (*SEM* = 1.06) in Group Animal, $t(58) = -1.09$, $p = .28$.

Figure 1 presents the mean proportion of trials on which stomach trouble was predicted in response to Z in context A1B1 across the eight blocks of the acquisition phase separated by groups. Black circles correspond to data from Group Color, white circles to data from Group Animal.

A Block (1 − 8) × Group (Color vs. Animal) repeated-measures analysis of variance (ANOVA) revealed a main effect of block, $F(7, 406) = 29.35$, $p < .001$, $\eta_p^2 = .34$, showing an increase of stomach trouble predictions to Z over the course of training. The main effect of group, $F(1, 58) = 1.55$, $p = .22$, and the interaction, $F < 1$, were not significant, indicating no differences between groups in performance to Z.

Figure 2 presents responding to Z in contexts A1B1, A1B2, and A2B1 during the test phase in terms of the mean proportion of stomach trouble predictions collapsed across the four presentations of Z in each context separated by groups. Left-hand bars represent data from Group Color, right-hand bars data from Group Animal. Within each group, the dark gray bar shows responding in the acquisition context A1B1, the light gray bar responding in context A1B2, and the white bar responding in context A2B1.

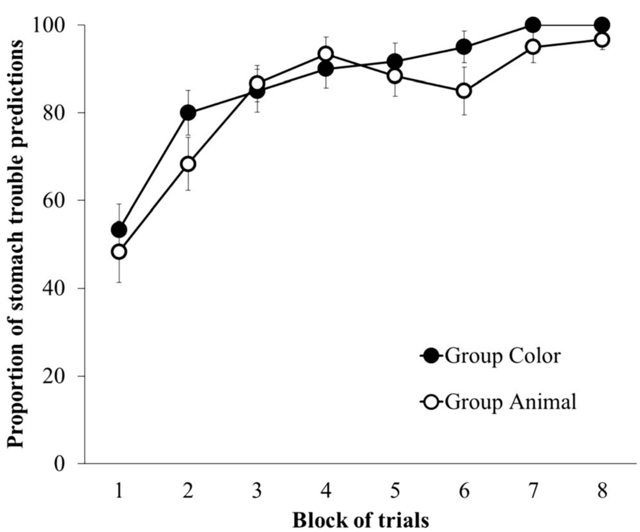

Fig. 1. Mean proportions of stomach trouble predictions to Z in context A1B1 across the eight blocks of the acquisition phase separated by groups. Error bars denote standard error of the means

A Context (A1B1, A1B2, A2B1) × Group (Color vs. Animal) ANOVA revealed a significant Context × Group interaction, $F(2, 116) = 4.17$, $p = .02$, $\eta_p^2 = .07$. The main effects of context, $F(2, 116) = 1.80$, $p = .17$, and of group, $F < 1$, were not significant.

To decompose the Context × Group interaction, we conducted planned comparisons using contrast analyses (*p* values were Bonferroni adjusted for multiple comparisons). The levels of the factor context (A1B1, A1B2, A2B1) received the contrast weights $\lambda = [1, 1, -2]$ to code for the hypothesis that a change of the acquisition context A1B1 along dimension A (A2B1) disrupts acquisition performance, but not a change along dimension B (A1B2). This contrast was significant for Group Color, $F(1, 58) = 6.06$, $p = .03$, but nonsignificant in case of Group Animal, $F(1, 58) = 1.84$, $p = .36$. For a second contrast, the factor levels of context received the contrast weights $\lambda = [1, -2, 1]$ coding the hypothesis that a change of the acquisition context along Dimension B disrupts acquisition performance, but not a change along Dimension A. The second contrast was nonsignificant for Group Color, $F < 1$, but reached significance in Group Animal, $F(1, 58) = 5.67$, $p = .04$.

Discussion

In the present experiment, participants acquired responding toward a target cue in a context composed of two elements from two dimensions, while additionally performing an *n*-back task for which context elements from one dimension were task-relevant and those from the other dimension were task-irrelevant. In a subsequent test, we observed that acquisition behavior toward the target cue was disrupted by changing the acquisition context along the dimension that was task-relevant for the *n*-back task. However, there was no evidence that acquisition was affected by changing the acquisition context along the dimension that was irrelevant for the *n*-back task. Our results are consistent with the idea that performance on the *n*-back task encouraged participants to pay more attention to context elements that were relevant for solving the task than to those that were task irrelevant, and that this difference in attention facilitated behavioral control by the former context elements compared to the latter.

Our results support the principle advocated by ATCP (Rosas et al., 2006) that context specificity of learning depends on attention allocated to contextual stimuli. In accordance with ATCP, previous research revealed that contextual control of behavior is influenced by several treatments supposed to alter attention to contexts via learning experience (e.g., León et al., 2010a, 2010b, 2011; Lucke et al., 2013; Rosas & Callejas-Aguilera, 2006, 2007). The present experiment extends these studies in an important way by demonstrating that context specificity of learning can be modulated by "nonlearning" treatments.

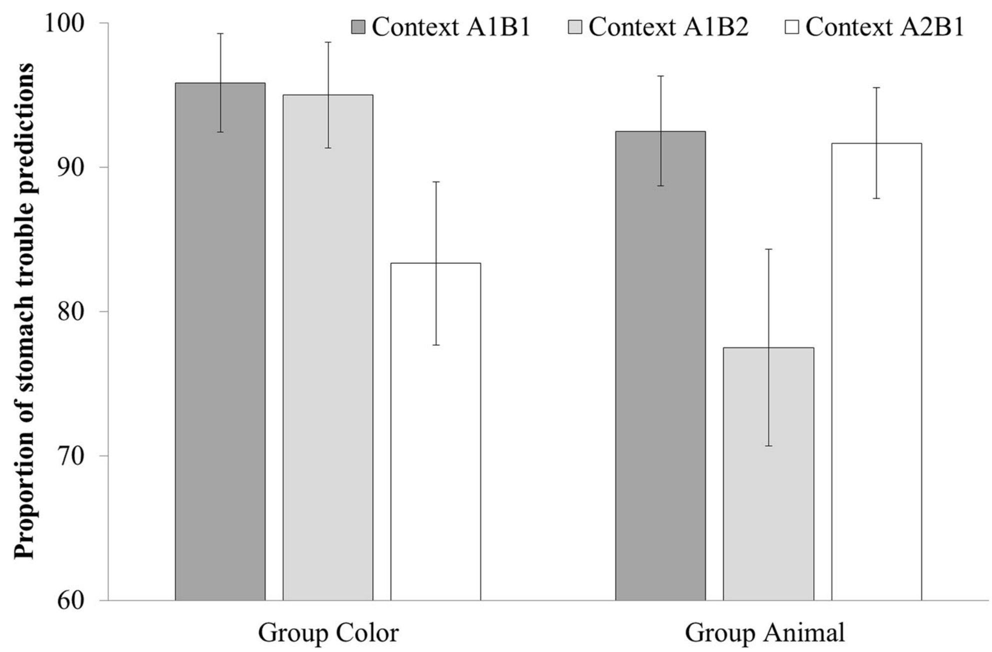

Fig. 2. Mean proportions of stomach trouble predictions to Z in contexts A1B1, A1B2, and A2B1, collapsed across the four presentations in each context during the test phase separated by groups. Error bars denote standard error of the means

If it is accepted that performance on the *n*-back task modulated the salience of the context elements, then the present results are compatible with a variety of associative learning models. Under this premise, our results are consistent with configural theories (e.g., Kinder & Lachnit, 2003; Kruschke, 1992; Pearce, 1994) assuming that the stimulation provoked by a particular configuration of stimuli results in one unitary representation that enters into associations with outcomes. A theoretical framework for the present results is also provided by hierarchical models (e.g., Bouton, 1993, 1994), suggesting that contexts modulate activation of entire cue–outcome associations. And, the assumption of differences in the salience of context elements reconciles our findings with unique-cue extensions of elemental theories (e.g., Rescorla & Wagner, 1972). According to this view, any combination of stimuli is encoded by representations of the individual elements and a cue that is unique to the specific stimulus conjunction. However, purely elemental theories cannot account for our results. This approach predicts for the present experiment that the context elements belonging to the same dimension should have acquired equal associative strengths, which makes it impossible to account for the context-specificity effect that we observed.

There is evidence suggesting that repeated presentations of a cue in a context establish a direct association between internal representations of the cue and the context (e.g., Marlin, 1982). For the present experiment, it is possible that cue–context associations may have modulated the ease with which participants detected contextual changes regarding the target cue. The circumstance that context elements that were relevant for solving the *n*-back task received more attention than those that were irrelevant may have resulted in a stronger association between the target cue and the task-relevant context element than between the cue and the task-irrelevant context element. Therefore, presentations of the target cue outside its original acquisition context may have been more surprising when the context change was achieved by replacing the task-relevant context element rather than the task-irrelevant context element.

Previous research provided evidence that the working memory load related to the *n*-back task induces changes in attention deployment (e.g., Rose et al., 2005; Simon et al., 2016). However, an application of these findings to the present experiment should be made with caution, as there are several procedural differences between the *n*-back task from the present experiment and those used in the previous studies (e.g., number of stimuli, presence and type of additional tasks). Therefore, future research will be required that manipulate the working memory load related to the *n*-back task, for instance, by manipulating the number of trials between the stimuli that have to be compared, and assess its impact on the context specificity of learning.

The present experiment is silent about the way in which performance on the *n*-back task may have established a difference in the salience of task-relevant and task-irrelevant context elements. Such a difference in salience might arise from increases of attention to task-relevant context elements, decreases of attention to task-irrelevant context elements, or both. Future research will be required to specify the dynamics of attentional changes, for instance, by considering a control condition for which the *n*-back task is omitted.

In the present experiment, we manipulated the psychological salience of context elements by training them as either relevant or irrelevant for the *n*-back task. According to ATCP (Rosas et al., 2006), differences in physical salience of context elements should also affect the context specificity of learning. The way in which humans and other animals allocate attention across environmental stimuli is influenced by bottom-up factors that are determined by physical properties of the stimuli. Stimuli with physical features that stand in contrast to the physical properties of neighboring stimuli are more likely to capture attention. For instance, attention deployment is biased in favor of stimuli with abrupt onsets (Yantis & Jonides, 1984), or stimuli that differ in their color from an otherwise uniformly colored set of stimuli (a red element among green elements; Theeuwes, 2004). Future research may investigate the impact of physical context salience on the context specificity of learning, which is necessary to further evaluate the generality of the principles advocated by ATCP.

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