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Relevance-Based Selectivity: The Case of Implicit Learning

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Learning the structure of the environment (e.g., what usually follows what) enables animals to behave in an effective manner and prepare for future events. Unintentional learning is capable of efficiently producing such knowledge as has been demonstrated with the Artificial Grammar Learning paradigm (AGL), among others. It has been argued that selective attention is a necessary and sufficient condition for visual implicit learning. Experiment 1 shows that spatial attention is not sufficient for implicit learning. Learning does not occur if the stimuli instantiating the structure are task irrelevant. In a second experiment, we demonstrate that this holds even with abundance of available attentional resources. Together, these results challenge the current view of the relations between attention, resources, and implicit learning.

Keywords: implicit learning, selective attention, spatial attention, perceptual load, task relevance, Artificial Grammar Learning

Humans, as other animals, benefit from knowing the regularities of their environment. When such regularities are acquired without intention, and largely without awareness, learning is often termed *implicit* (Reber, 1967; for reviews see Frensch, 1998; Frensch & Runger, 2003; Reber, 1993). The processes responsible for such learning were once contrasted with a selective, intentional "system" (e.g., Hayes & Broadbent, 1988). However, more recent research shows that implicit learning processes are in fact highly selective (Tanaka et al., 2008; Jiménez & Mendez, 1999; Jiang & Chun, 2001; Turk-Browne, Junge, & Scholl, 2005; but see Guo et al., 2013).

In an attempt to investigate this selectivity, our own past research on implicit learning targeted the effects of the learner's motivation. We showed that both the amount (Eitam, Hassin, & Schul, 2008) and direction (Eitam, Schul, & Hassin, 2009) of implicit learning are modulated by motivation. Moreover, we (Eitam et al., 2008) highlighted the importance of task relevance above and beyond mere spatial attention as a basis for stimulus selection in implicit learning (See also Frensch & Runger, 2003). Using Artificial Grammar Learning we presented both relevant and irrelevant features of stimuli (color relevant vs. shape relevant) within participants' attentional focus. We found that only the grammar instantiated by the relevant features was implicitly learned.

Yet, as task relevance is considered to lead the deployment of attention (Folk, Remington, & Johnston, 1992), and because relevance was bound to a feature in these studies, one could argue that relevance affected implicit learning through *recruiting* dimension/feature-based attention (e.g., Kumada, 2001; Rossi & Paradiso, 1995). Hence these data do not enable us to pinpoint the effect of relevance on implicit learning, over and above attention per se. In other words, the data above cannot tell us whether spatial attention in and of itself (i.e., regardless of relevance) is a sufficient condition for implicit learning to occur.

The Current Study

Building on a framework developed for explaining selectivity in activation of semantic knowledge (Eitam & Higgins, 2010; Eitam, Miele, & Higgins, in press), we argue that knowledge activation is modulated by the relevance of the represented information to task demands and that irrelevant information is largely unavailable to cognitive process. Hence, implicit learning is likely to occur only for relevant information. Specifically, we hypothesize that implicit learning will occur only when objects, features, or locations are task relevant. In other words, if these were attended but not relevant, learning would not take place. Attention, then, is not a sufficient condition for implicit learning.

To directly test the role of relevance in implicit learning we created conditions in which current theories of attention would predict that stimuli would be processed (and hence learning would occur). Specifically, like Eitam et al. (2009), we manipulated

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spatial relevance *within the spotlight*. Unlike Eitam et al., however, the task-relevant and task-irrelevant stimuli belonged to the same dimension. Accordingly, selection could not be based on the stimulus' dimension, and hence the effect of relevance is far less likely to occur through recruitment of feature-based attention. Note, further, that the modal views of attention holds that allocation of spatial attention behaves somewhat like a spotlight (see, e.g., Broadbent, 1982; Posner, Snyder, & Davidson, 1980) or a zoom lens (Eriksen & James, 1986; Eriksen & Yeh, 1985). Hence, a certain amount of attention should be allocated to any stimulus that falls within the spotlight/lens. Our current experiments, then, provide a strong test for the hypothesis that attention per se is not sufficient for implicit learning, and that the structure of task-irrelevant stimuli in the focus attention is not learned implicitly.

Given that the availability of attentional resources is considered a necessary and sufficient condition for them to spill over to spatially irrelevant stimuli, Experiment 2 directly tests whether the task-relevance selection occurs also when cognitive resources were plentiful (cf., Lavie, 1995; Lavie & Cox, 1997).

In ending this brief introduction, it should be noted that the role of attention in implicit learning has been studied by many groups, with mixed results that do not easily yield to a single theoretical explanation. Some of this confusion stems from the multiple uses of the term *attention* itself (e.g., as selection vs. as resource). By deriving our predictions from prominent theories of attention, we aim to facilitate the integration of findings on "attention in implicit learning" with the more general literature on attention. In the General Discussion we will succinctly discuss prime examples and show how the current framework contributes to a general understanding of the relation between attention and implicit learning, and how this understanding maps on to selection in general.

Experiment 1: Location Relevance-Based Selection Within the Spotlight

Method

Participants. Eighty Hebrew University undergraduates (54 females, mean age = 23.6, *SD* = 2.5) participated in the experiment in exchange for course credit or pay. Participants were run individually and were randomly assigned to one of two relevance conditions, 40 per condition. One participant was excluded from analysis because he did not adhere to the instructions.

Stimuli. Stimuli were based on two different finite-state grammars, similar in their complexity, each containing eight potential paths between nodes and two recursions (see Figure 1). Ten colors were selected for maximal differentiation among themselves; five were randomly allocated to the outer circle and another five to the inner circle. The colors were then assigned to each node. Each of these grammars can generate a total of 52 unique five–nine-colors-long sequences for each grammar. For the familiarization phase, 32 sequences from each grammar (the same ones used by Dienes, Altman, Kwan, & Goode, 1995 and by Eitam et al., 2009) were randomly combined, with the restriction that the sequences have equal length to from sequences of concentric circles (see Figure 2a).[1] During the test phase, participants saw 40 novel sequences comprised of either

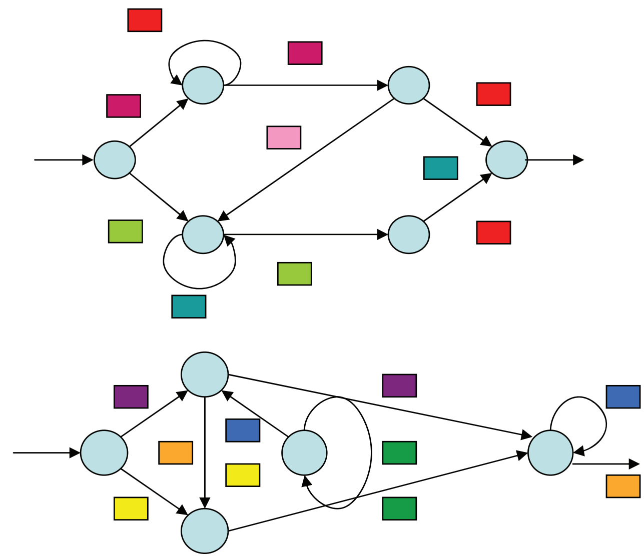

Figure 1. The two grammars used for generating the training and test stimuli (Grammars adapted from those used by Dienes et al., 1995).

outer- or inner-circles. For the outer-circles test sequences, 20 obeyed the outer-grammar used during familiarization, while 20 obeyed the inner-grammar used during familiarization and violated the outer-grammar. The exact opposite held for participants who saw the inner-grammar test sequences. To be clear, both "grammatical" and "nongrammatical" strings were colored in the colors of the to-be-tested grammar. That is, participants could in no way establish the grammaticality of an item based on its colors, but only on their ordering.

Procedure. The experiment included three phases: practice, training, and a (surprise) grammar test.

Practice. During practice, participants learned how to use a color matrix employed during the training phase (see Figure 2b). To prepare them for using this mode of response, they went through two stages of practice prior to the main experiment. Practice began by responding to a series of color patches that stayed on the screen until the participant responded (30 trials) and received feedback on their performance. Next, they were given three practice sequences of colored concentric circles that were to be memorized. The colors of these sequences were determined randomly for both the inner and outer circles. For each sequence, participants were requested to recall the colors of either of the inner or outer circles, according to their experimental condition, and received feedback on the success of their memory performance. Participants produced the sequence of colors they remembered using the color matrix.

Training. During the training phase, participants viewed strings of concentric circles in the center of the screen, one at a time, for 7 seconds each, with an ISI of one second between two successive trials (Eitam et al., 2009). To manipulate relevance of a location, half of the participants were instructed to memorize the

[1] In order to rule out possible effect of specific combinations, individual strings were randomly combined to create 96 potentially different combinations, with each individual string appearing three times.

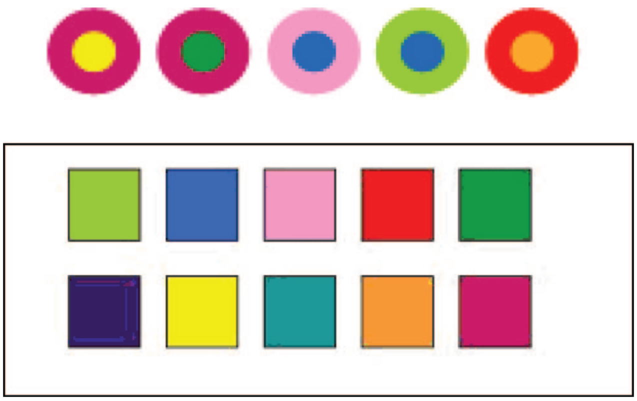

Figure 2. a. A training stimulus in Experiment 1. b. The color matrix participants used for responding.

inner (outer) circles.[2] Each individual string appeared three times and the order of strings was randomly determined for each participant, with the provision that the same string did not appear on consecutive trials. To ensure that participants actually looked at the stimuli, a memory probe appeared after 33 of 96 trials (34 participants responded to the memory probes by clicking on a color matrix that appeared on the computer screen. The order of the colors in the color-matrix was randomly assigned for each participant.[3]

Grammar test. A surprise test phase followed training. Participants were informed that sequences of the inner (outer) circles adhered to a complex set of rules. On each trial, a single test sequence was presented in the center of the screen until participants responded, and participants were asked to determine whether the stimuli followed these rules or not. To foster application of implicit knowledge, participants were told that the rules were very complex and were encouraged to use their "gut feeling" when classifying the novel strings (see, e.g., Dienes et al., 1995).

Results

Grammatical knowledge. A two-way ANOVA with Memorized Location (inner circle vs. outer circle) and Test Relevance (relevant vs. irrelevant) as between-participants factors was performed. The relevance effect was significant, $F(1, 76) = 48.2$, $p < .01$.[4] Participants who were tested on a grammar that was instantiated in a task-relevant location classified the sequences with a mean percentage rate of 64%, $SD = 13$, which is reliably higher than chance-level performance (50%) $t(39) = 6.81$, $p < .001$; in marked contrast, participants who were tested on the grammar that was instantiated in an irrelevant location during the training phase performed at a rate no reliably different than chance level, with a mean percentage rate of 47.5%, $SD = 6$, $t(39) = -1.6$, $p = .1$. It is important that there was no difference between participants that attended the inner and outer strings (see Table 1 for the individual cells). Thus, whether an irrelevant color was at the center or the periphery of the spotlight did not make any difference—in both cases spatially irrelevant stimuli did not lead to learning. Finally, we explored whether the effect of relevance is driven by a small subset of test items. This was clearly not the case (see Figure 3), as classification performance was nominally superior in 32 of the 40 test items (80%) when they adhered or violated a grammar instantiated in a relevant (vs. irrelevant) location.

Explicit memory for training items. Some authors have argued that implicit learning is no more than a manifestation of explicit, albeit fragmentary, memorization of instances (Brooks, 1978; Jamieson & Mewhort, 2010). If this was indeed the case, the effect of relevance we are reporting should be attributed to explicit rather than implicit learning. To test this idea empirically, we explored the relationship between the participants' explicit-memory performance in the training task and their success in learning of the structure implicitly (as assessed by the grammar test). For each participant, we computed the percentage of correct hits for each of the 33 strings that the participant was asked to recall, with a hit referring to the correct color in its correct location. For example, if a participant correctly recalled four colors in their right location out of a sequence of eight colors, her score for that sequence was 50%. The accuracy of each participant is the mean of these scores (based on the 33 memory probes). On average, participants' accuracy score was 55% ($SD = 15.4$). Accuracy did not differ as a function of having to memorize the inner or the outer sequence; $M_{\text{inner}} = 52.9\%$ ($SD = 14.6$), and $M_{outer} = 56.9\%$ ($SD = 16$), $t(78) = -1.17$, $p = .24$. The question of interest is whether participants who are more successful in memorizing the color strings during training also succeed more in learning the grammar. We found no support for this hypothesis. Participants who were more accurate in memorizing the relevant training sequence were not significantly better in the grammar test than those who had poorer memory, *Pearson's* $r = .19$, $p = .22$.[5]

Participants were asked during the debriefing session, immediately after the experiment, about their intention to learn the structure of both relevant and irrelevant dimensions. Attesting to the

[2] Although the dimension (color) is held constant the features (colors) in the two locations always differed. One could argue that in the current study, selection could be feature-based (the different colors). We see a number of reasons for the mind/brain to select on the basis of (i.e., assign relevance to) a location rather than to a feature under the conditions of the current study. First, the instructions explicitly made location the carrier of relevance and most participants, we assume, try to follow instructions; second, participants did not know in advance what the identity and number of the relevant (or irrelevant) colors were and hence could actually never be sure of the actual set of relevant colors by mere observation; third, selection on the basis of a 5-item size would presumably be more difficult than selecting on the basis of a single location; fourth, findings show that selection within a dimension is difficult (e.g., Magen & Cohen, 2007).

[3] We note in brief that although in AGL memorization of the training strings is often used as a method to control participants' engagement with the task, explicit rehearsal is not a necessary condition for structure learning to occur (see also Experiment 2). Implicit learning was demonstrated using both "attend" and "observe" instructions (Conway & Christiansen, 2006; Reber & Allen, 1978; Vokey & Brooks, 1992), and through mere copying/liking judgments of the training stimuli (McAndrews & Moscovitch, 1985).

[4] The effect of Spatial Location was also significant, $F(1, 76) = 3.88$, $p = .05$. Within the relevant condition, participants performed better for the outer compared to the inner sequences. This effect was not predicted and was not replicated in another experiment (not reported) so we do not discuss it further.

[5] Although we cannot rule out the possibility that the grammar test depends solely on LTM process while our memory measure depends solely on WKM, it is not highly plausible. First, there is evidence that LTM and WKM are related (Baddeley & Hitch, 1974); second, the possibility that any single measure is process pure is itself highly unlikely (e.g., Yonelinas, 2001).

Table 1
Experiment 1 Percent Correct by Grammar and Location Relevance Factors

	Relevance of the tested sequence	
	Relevant	Irrelevant
Memorized location in training		
In	60.5 (13)	48.0 (8)
Out	69.0 (13)	47.5 (7)

success of our manipulation of task relevance, participants reported a stronger intention to learn the relevant dimension, M_{rel} = 4.90, SD = 2.48, M_{irrel} = 2.20, SD = 2.45; $t(70) = 4.7$, $p < .05$, as it served their explicit goal. It is important, though, that differences in the intention to learn did not reliably predict participants' grammar learning ($r = .15$, $p = .7$ for the relevant conditions).[6] This is consistent with the definition of the learning in this experiment as implicit.

Discussion

Participants were presented with strings of concentric circles, with the colors in the outer and the inner circles adhering to different grammars. AGL occurred only for color sequences that appeared in task-relevant locations, even when both were within the spotlight. The current data suggest relevance is necessary for implicit learning. Moreover, task relevance is necessary even for stimuli that is in the focus or spotlight of spatial attention and hence, presumably, received some amount of attention. The results also show that learning the grammar was statistically unrelated to participants' intention to learn the structure or to the extent of their explicit memory of the individual instances. This is consistent with the assumption that the learning is unintentional.

It might be argued that although the task-irrelevant stimuli could potentially receive attention being at in the focus of attention they did not, simply because the task was demanding enough to consume all available spatial attentional resources, leaving none to spill over to the irrelevant sequences. In fact, the corroboration of this prediction is central to one of the currently prominent theories of attentional selection, Perceptual-Load theory (e.g., Lavie, 1995; Lavie & Cox, 1997).

To directly test this possibility, we ran Experiment 2, in which the stimuli that instantiated the structure were presented under minimal load. Specifically, unlike Experiment 1, each concentric circle was shown individually for a duration of 500 ms with an interval of 500 ms between the presentation of successive concentric circles (see Figure 3). Because there was only one stimulus at a time, perceptual load was minimal. If task relevance serves mainly to prioritize the investment of attention and is not a necessary condition for learning, then under these load-less conditions implicit learning of the irrelevant grammar should appear.

In a recent study, Eitam, Yeshurun, and Hassan (2013) used similar stimuli (two colored concentric circles) that were presented for 500 ms. Five hundred milliseconds after stimulus offset participants were asked to recognize the color that had appeared in both relevant and irrelevant locations (order counterbalanced). They reported that over 75% of their participants were able to report the color that appeared in the irrelevant location. Based on this, it would be only reasonable to expect implicit learning of the irrelevant location. To anticipate our findings, Experiment 2, which uses highly similar stimuli and exactly the same durations, shows that this is not the case, and that task relevance is essential for implicit learning even when attentional resources are abundant.

Experiment 2: Testing for Relevance-Based Selection Under Minimal Load

Method

Participants. Forty-two participants (Average age = 27; 25 female) from University of Haifa participated for either course credit or payment (~$5). Participants were run individually and were randomly assigned to one of two conditions, 21 in each condition.

Procedure. As Experiment 1, this experiment consisted of three phases: practice, training, and test. Practice and training were modified as explained below.

Practice. Participants were shown five sequences of five concentric circles. Unlike Experiment 1, each concentric circle was shown alone for a duration of 500 ms with an interval of 500 ms. between the presentation of successive concentric circles. During practice, the color sequences (both inner and outer) of the circles were random; that is, they were not based on any grammar. Also, the order of the circles within a sequence was randomly determined. At the end of each sequence, a black screen appeared for the duration of 500 ms. Participants were instructed that after each black screen they will be asked to tell us what was the color of the outer circle of the stimulus that immediately preceded the last stimulus. To enable them to do so, the black screen was replaced by a matrix of colors (consisting of all the 10 colors used in the experiment). Participants used the mouse to indicate their choice. If participants erred, the practice was repeated until the correct response was obtained.

Training phase. Ninety-six unique sequences of five concentric circles were presented in three blocks. Each block consisted of 32 sequences shown in a random order. Unlike the sequences used during the practice, the sequences of colors in the inner and the outer circles used during the training conformed to the two different grammars used in Experiment 1. The task was identical to that of the practice phase; at the end of each sequence, participants were to indicate the color of the outer circle that immediately preceded the last stimulus using the response color matrix. However, unlike the practice, they consisted of only the five colors of the outer circles (see Figure 4 for an example sequence). Participants were given feedback about the accuracy of their response; errors were minimal at 7%. At the end of each block, there was a self-paced break to maintain their engagement with the task. Importantly, no mention of the existence of any form of sequences was made.

Test phase. Following training, half of the participants were informed that the outer color sequences adhered to a very complex set of rules (Relevant Grammar condition); the other half were informed that the inner color sequences adhered to a set of complex rules (Irrelevant Grammar condition). Participants were then

[6] Due to technical problems, eight of the questionnaires were lost.

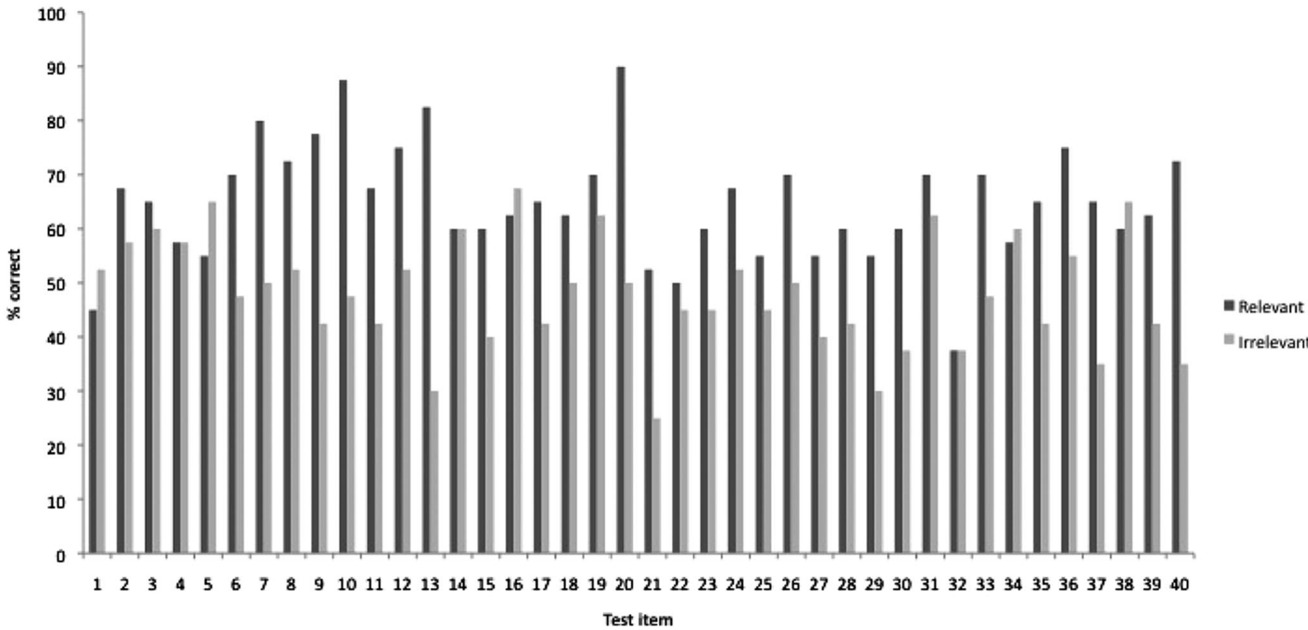

Figure 3. Experiment 1: The effect of relevance on classification performance by test item; note that chance level performance is at 50%. In 32 of the 40 items (80%), a test item based on a grammar that was instantiated in a relevant (vs. irrelevant) location was better categorized. Thus, the effect of relevance on grammar learning is very reliable.

asked to categorize 40 new sequences as either grammatical or not. Sequences in the test phase were composed of either the outer (Relevant Grammar condition) or inner (Irrelevant Grammar condition) colors; thus, the outer color sequences appeared with a white inner circle, and the inner color sequences appeared with no outer color. The sequences were shown one circle at a time, as during training. Following the appearance of each test sequences, the question appeared on screen until participants responded (1−grammatical, 2−ungrammatical). No feedback was given during this phase. As in Experiment 1, both grammatical and ungrammatical items were comprised from the colors appropriate for that location, hence participants could in no way categorize grammati-

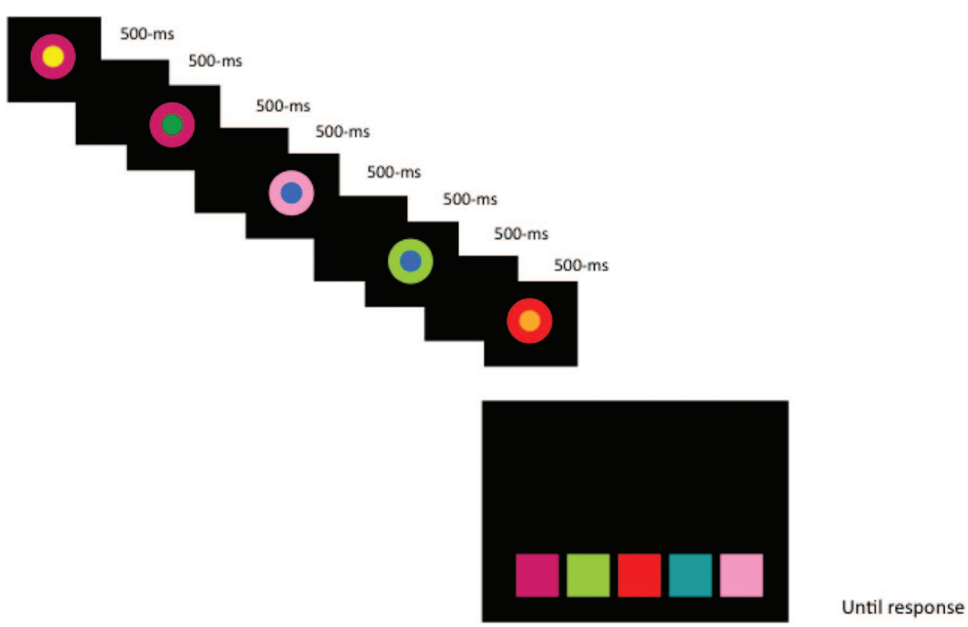

Figure 4. An example sequence in the training phase of Experiment 2. Note the response box contained 10 colors during practice and five colors (as shown) during training. Participants were given feedback on error.

cality on the basis of the existence of a specific color but only by the order of colors.

Results

Knowledge of grammar. Participants who classified sequences based on the relevant grammar (i.e., the grammar of the outer colors) were correct in 63.7% ($SD = 16$), showing reliable learning as compared to chance, $t(20) = 3.9$, $p < .01$. In contrast, participants who were tested on the irrelevant grammar—that is, on the grammar of the inner colors—showed no reliable learning, with a mean percent correct of 53% ($SD = 9.5$), $t(20) = 1.5$, $p = .1$. An independent-samples *t* test comparing the grammar knowledge of the Relevant and Irrelevant conditions also revealed a reliable difference between them, with a mean difference of 10%, $t(40) = 2.58$, $p < .02$.

In summary, Experiment 2 revealed once again that the grammar that underlies task-irrelevant stimuli is not learned implicitly even though the demand for attentional resources was minimized. We thus conclude that task relevance is a necessary condition for implicit learning even given attention, at least in the current paradigms.

General Discussion

The results of two experiments provide strong evidence for the role that task relevance plays in implicit learning over and above spatial attention, and propose some surprising implications for current theories of attentional selection. Whereas Eitam et al., (2009) demonstrated that AGL occurs for task-relevant features when the relevant and the irrelevant are represented by different dimensions (letters vs. colors) and selection occurred under heavy perceptual load, the current study provides the first direct evidence that AGL occurs only for task-relevant locations even when both the irrelevant and the relevant locations are in the focus of spatial attention (Experiment 1), and even when attentional resources are clearly available (Experiment 2).

Before we explore the implications of these findings, let us briefly discuss a number of possible alternative interpretations of the data. First, consider the suggestion that the relevance manipulation merely assigned attention to an object (e.g., the inner circle). Our findings cannot rule out this interpretation. Yet, we believe that it is less plausible in light of Eitam et al. (2013), in which selection largely failed when similar stimuli were used in a considerably easier perceptual task. Moreover, an object-based attention mechanism has to contend with the failure of selection within the spotlight in a variety of other tasks, even when stimuli are clearly "different objects" (e.g., in the standard Flanker task; Eriksen & Eriksen, 1974). Note that we are not arguing that all the stimuli within the spotlight receive the same amount of attention. Rather, we propose stimuli under the spotlight receive some spatial attention, and that this attention alone is not enough for implicit learning to occur.

Alternatively, it might be argued that relevance affects the amount of attention that is allocated. According to this account of our findings, relevance insures that sufficient attention is allocated to a stimulus, rather than merely selecting it (as the first attentional explanation would hold). The reason that no implicit learning occurs for irrelevant stimuli even though attention was clearly available (as in Experiment 2) is that the necessary amount of attentional resources was not allocated to the irrelevant stimuli.

The viability of this account hinges upon the assumption that implicit learning is sensitive not only to selection but also to the amount of attention allocated to the structure-instantiating stimuli. However, empirical evidence shows that, by and large, implicit learning is insensitive to the amount of attention that is paid to the stimuli. For example, using a modification of the Contextual Cuing Paradigm (an implicit learning task), Rausei, Makovski, and Jiang (2007) demonstrated that the quality of implicit learning of a perceptual context does not change with the amount of attention individual stimuli receive (for similar demonstrations see also Coomans & colleagues, 2011;[7] Rowland & Shanks, 2006). Building on previous work demonstrating that a search among target-similar context leads to more attentional engagement with the stimuli (i.e., more attention allocation; Duncan & Humphreys, 1989), Rausei et al. were able to show that target-similar contexts (more attention to the to-be-learned context) did not produce significantly more implicit learning than target-dissimilar ones (less attention to the to-be-learned context).

A third alternative account of our findings is that the shape of the attentional spotlight is more flexible than thought before (e.g., Müller & Hubner, 2002). In particular, one may argue that it might be shaped like a bagel. If so, participants may have somehow found a way to focus their spatial attention exclusively on the location of the relevant stimuli. While this possibility cannot be directly ruled out by our results, it conflicts with abundant data showing obligatory processing within the spotlight (for reviews see Broadbent, 1982; Eriksen & James, 1986). Furthermore, dominant depictions of the link between attention and selection would still entail that the available resources should "spill over" to the irrelevant stimuli regardless of the shape of the spotlight (Cartwright-Finch & Lavie, 2007; Duncan & Humphreys, 1989; Lavie, 2006; Macdonald & Lavie, 2008).

At least with respect to implicit learning, we find the relevance-based explanation more parsimonious because it helps to accommodate a large body of findings with relatively few assumptions. In particular, since relevance can be assigned to objects, features, locations, or knowledge structures (elements of the to-be-learned invariance itself) and to all that covaries with such relevant elements, a relevance-based explanation can accommodate the multitude of currently unexplainable results without a need to resort to multiple mechanisms. For example, implicit learning has been shown to occur when stimuli are supposedly ignored and when locations are unattended. Specifically, implicit learning of ignored stimuli was demonstrated using a modified version of the Contextual Cuing Paradigm mentioned above (Chun & Jiang, 1998, 2003). Moreover, Jiang and Leung (2005) were able to show that the unattended distractor contexts were actually learned implicitly, but not expressed. It should be noted that although the nontarget colored context was unattended, it was in fact task relevant—as it too predicted the target's location.

Using a different implicit-learning paradigm, Cock and colleagues (2002; see also Deroost, Zeischka & Soetens, 2008; Row-

[7] Differing from the CCP, the to-be-learned structure in this case was the "irrelevant" sequence of locations. As the task required identification of the target it seems reasonable to argue that its location was in fact relevant.

land & Shanks, 2006; Experiment 1) showed that unattended stimuli are learned. They used a modified Serial Reaction Time task (SRT) to demonstrate implicit learning of sequences of locations. Participants were to attend a stimulus that was marked by one colored dot and ignore another stimulus marked by a different colored dot (e.g., a blue dot for "attend" and a red one for "ignore"). After training, participants were asked to respond to stimuli appearing in the previously ignored sequences of locations or in different (new) sequences of locations. Participants showed a clear advantage for responding to stimuli presented in the previously ignored sequences demonstrating that they had learned their structure. Again, although the nontarget stimulus was by itself task irrelevant, its location was relevant as it was (negatively) correlated with target's location and hence we would predict that it would be learned. That is, given that the two (target and nontarget) stimuli could not simultaneously appear in the same location, the nontarget sequence was informative about the location of the target.

In yet another demonstration of relevant stimuli being implicitly learned even without attention, Jiménez & Vazquez (2011; Experiment 3a), using a task that combined a Serial Reaction Time task with a Contextual Cuing paradigm, found that contexts are implicitly learned even when they are "highly unlikely to be attended" (i.e., when target location is completely predictable and distracters can be rejected preattentively). Here too, although distracters are argued to be rejected preattentively—they were task relevant (albeit redundant), as they consistently predict the target's location.[8]

Finally, as the regularity itself may be task relevant (as in the Contextual Cuing paradigm, in which the pattern itself predicts the location of the target) the proposed role task relevance plays in implicit learning may explain studies showing currently unexplainable implicit learning *that leads to allocation of attention* (see Zhao, Al-Aidroos, & Turk-Browne, 2013).

To summarize, the current study shows that task relevance is a crucial factor in implicit learning of attended stimuli. When implicit learning is concerned, no learning of irrelevant information was detected even when the individual clearly had sufficient attentional resources to acquire all the structures that existed in the "environment" we created. Other studies show that attention may also not be necessary for implicit learning to occur. These results provide support for the importance of considering relevance per se for learning and cognition at various levels of processing (Eitam & Higgins, 2010).

[8] We intentionally begin with minimal explanatory machinery. A better, but less parsimonious, relevance-based explanation for these results is that implicit learning occurs for task-relevant stimuli and for stimuli that covary with task-relevant stimuli.

References

Baddeley, A. D., & Hitch, G. J. (1974. Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation,* (Vol. 8, pp. 47–89). New York, NY: Academic Press.

Broadbent, D. E. (1982). Task combination and selective intake of information. *Acta Psychologica, 50,* 253–290. doi:10.1016/0001-6918(82)90043-9

Brooks, L. R. (1978). Non-analytic concept formation and memory for instances. In E. Rosch, (Ed.), *Cognition and concepts* (pp. 169–211). Hillsdale, NJ: Erlbaum,

Cartwright–Finch, U., & Lavie, N. (2007). The role of perceptual load in inattentional blindness. *Cognition, 102,* 321–340. doi:10.1016/j.cognition.2006.01.002

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36,* 28–71. doi:10.1006/cogp.1998.0681

Chun, M. M., & Jiang, Y. (2003). Implicit, long-term spatial contextual memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 224–234. doi:10.1037/0278-7393.29.2.224

Cock, J. J., Berry, D. C., & Buchner, A. (2002). Negative priming and sequence learning. *European Journal of Cognitive Psychology, 14,* 27–48.

Coomans, D., Deroost, N., Zeischka, P., & Soetens, E. (2011). On the automaticity of pure perceptual sequence learning. *Consciousness and cognition, 20*(4), 1460–1472

Conway, C. M., & Christiansen, M. H. (2006). Statistical learning within and between modalities. *Psychological Science, 17,* 905–912. doi:10.1111/j.1467-9280.2006.01801.x

Deroost, N., Zeischka, P., & Soetens, E. (2008). Negative priming in the SRT task: Learning of irrelevant sequences is enhanced by concurrent learning of relevant sequences. *European Journal of Cognitive Psychology, 20,* 47–68. doi:10.1080/09541440701282159

Dienes, Z., Altman, G. T. M., Kwan, L., & Goode, A. (1995). Unconscious knowledge of artificial grammars is applied strategically. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1322–1338. doi:10.1037/0278-7393.21.5.1322

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96,* 433–458. doi:10.1037/0033-295X.96.3.433

Eitam, B., Hassin, R. R., & Schul, Y. (2008). Non-conscious goal pursuit in novel environments: The case of implicit learning. *Psychological Science, 19,* 261–267. doi:10.1111/j.1467-9280.2008.02078.x

Eitam, B., & Higgins, E. T. (2010). Motivation in mental accessibility: Relevance Of A Representation (ROAR) as a new framework. *Social & Personality Psychology Compass, 4,* 951–967. doi:10.1111/j.1751-9004.2010.00309.x

Eitam, B., Miele, D. B., & Higgins, E. T. (in press). Motivated remembering: remembering as accessibility and accessibility as motivational relevance. In D. Carlston (ed.), *Handbook of social cognition*. Oxford University Press, New York.

Eitam, B., Schul, Y., & Hassin, R. R. (2009). Goal relevance and artificial grammar learning. *The Quarterly Journal of Experimental Psychology, 62,* 228–238. doi:10.1080/17470210802479113

Eitam, B., Yeshurun, Y., & Hassan, K. (2013). Blinded by irrelevance: Pure irrelevance induced blindness. *Journal of Experimental Psychology: Human Perception and Performance, 39,* 611–615. doi:10.1037/a0032269

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149. doi:10.3758/BF03203267

Eriksen, C. W., & James, J. D. S. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225–240. doi:10.3758/BF03211502

Eriksen, C. W., & Yeh, Y. Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 583–597. doi:10.1037/0096-1523.11.5.583

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1030–1044. doi:10.1037/0096-1523.18.4.1030

Frensch, P. (1998). One concept, multiple meanings: On how to define the concept of implicit learning. In M. A. Stadler & P. A. Frensch (Ed.), *Handbook of implicit learning* (pp. 47–104). Thousand Oaks, CA: Sage.

Frensch, P., & Runger, D. (2003). Implicit learning. *Current Directions in Psychological Science, 12,* 13–18. doi:10.1111/1467-8721.01213

Guo, X., Jiang, S., Wang, H., Zhu, L., Tang, J., Dienes, Z., & Yang, Z. (2013). Unconsciously learning task-irrelevant perceptual sequences. *Consciousness and Cognition, 22,* 203–211. doi:10.1016/j.concog.2012.12.001

Hayes, N. A., & Broadbent, D. (1988). Two modes of learning for interactive tasks. *Cognition, 28,* 249–276. doi:10.1016/0010-0277(88)90015-7

Jiang, Y., & Chun, M. M. (2001). Selective attention modulates implicit learning. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 54,* 1105–1124. doi:10.1080/02724980042000516

Jiang, Y., & Leung, A. W. (2005). Implicit learning of ignored visual context. *Psychonomic Bulletin & Review, 12*(1), 100–106

Jiménez, L., & Mendez, C. (1999). Which attention is needed for implicit sequence learning? *Journal of Experiment Psychology: Learning, Memory, and Cognition, 25,* 236–259. doi:10.1037/0278-7393.25.1.236

Jiménez, L., & Vázquez, G. A. (2011). Implicit sequence learning and contextual cueing do not compete for central cognitive resources. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 222–235. doi:10.1037/a0020378

Kumada, T. (2001). Feature-based control of attention: Evidence for two forms of dimension weighting. *Perception & Psychophysics, 63,* 698–708. doi:10.3758/BF03194430

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 451–468. doi:10.1037/0096-1523.21.3.451

Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain Research, 1080,* 91–100. doi:10.1016/j.brainres.2005.10.023

Lavie, N., & Cox, S. (1997). On the efficiency of attentional selection: Efficient visual search results in inefficient rejection of distraction. *Psychological Science, 8,* 395–398. doi:10.1111/j.1467-9280.1997.tb00432.x

McAndrews, M. P., & Moscovitch, M. (1985). Rule-based and exemplar-based classification in artificial grammar learning. *Memory & Cognition, 13,* 469–475.

Macdonald, J. S. P., & Lavie, N. (2008). Load induced blindness. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 1078–1091. doi:10.1037/0096-1523.34.5.1078

Magen, H., & Cohen, A. (2007). Modularity beyond perception: Evidence from single task interference paradigms. *Cognitive Psychology, 55,* 1–36. doi:10.1016/j.cogpsych.2006.09.003

Müller, M. M., & Hubner, R. (2002). Can the spotlight of attention be shaped like a doughnut? Evidence from steady-state visual evoked potentials. *Psychological Science, 13,* 119–124. doi:10.1111/1467-9280.00422

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109,* 160–174. doi:10.1037/0096-3445.109.2.160

Rausei, V., Makovski, T., & Jiang, Y. (2007). Attention dependency in implicit learning of repeated search context. *Quarterly Journal of Experimental Psychology, 60,* 1321–1328.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6,* 855–863.

Reber, A. S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconscious*. New York, NY: Oxford University Press.

Reber, A. S., & Allen, R. (1978). Analogic and abstraction strategies in synthetic grammar learning: A functionalist interpretation. *Cognition, 6*(3), 189–221.

Rossi, A. F., & Paradiso, M. A. (1995). Feature-specific effects of selective visual attention. *Vision Research, 35,* 621–634.

Rowland, L. A., & Shanks, D. R. (2006). Attention modulates the learning of multiple contingencies. *Psychonomic Bulletin & Review, 13,* 643–648.

Tanaka, D., Kiyokawa, S., Yamada, A., Dienes, Z., & Shigmasu, K. (2008). Role of selective attention in artificial grammar learning. *Psychonomic Bulletin & Review, 15,* 1154–1159. doi:10.3758/PBR.15.6.1154

Turk-Browne, N. B., Junge, J. A., & Scholl, B. J. (2005). The automaticity of visual statistical learning. *Journal of Experimental Psychology: General, 134,* 552–564. doi:10.1037/0096-3445.134.4.552

Vokey, J. R., & Brooks, L. R. (1992). Salience of item knowledge in learning artificial grammars. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(2), 328.

Yonelinas, A. P. (2001). Consciousness, control, and confidence: The 3 Cs of recognition memory. *Journal of Experimental Psychology: General, 130,* 361–379.

Zhao, J., Al-Aidroos, N., & Turk-Browne, N. B. (2013). Attention is spontaneously biased toward regularities. *Psychological science, 24,* 667–677. doi:10.1177/0956797612460407.

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