Unconscious Detection of Implicit Expectancies

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Abstract

The detection of unexpected events is a fundamental process of learning. Theories of cognitive control and previous imaging results indicate a prominent role of the prefrontal cortex in the evaluation of the congruency between expected and actual outcomes. In most cases, this attributed function is based on results where the person is consciously aware of the discrepancy. In this functional magnetic imaging (fMRI) study, we examined violations of predicted outcomes that did not enter conscious awareness. Two groups were trained with nearly identical material and the effects of new stimuli were assessed after learning. For the first group, the material was arranged with a hidden regularity. In this incidental learning situation, volunteers acquired implicit knowledge about structural response regularities as was demonstrated by a decrease in reaction time when introducing new stimuli that violated the learned relations. To differentiate the detection process of stimuli that deviate from learned expectations from more unspecific effects generated by novel, unfamiliar stimuli, the second group was trained with rearranged material without a hidden regularity. No behavioral effects were found for the introduction of new stimuli in the group without implicit learning. Comparing the two groups, specific fMRI effects concerning the violation of implicitly learned expectations were found in the ventral prefrontal cortex and in the medial-temporal lobe.

In accord with theories of learning, the results show a direct influence of the detection of prediction errors on the neuronal activity in learning-related structures even in the absence of conscious knowledge about the predictions or their violations.

INTRODUCTION

Associative learning of constant relations in the environment results in the ability to predict upcoming events. The detection of an event deviating from the anticipated event is a fundamental mechanism of learning. Such unexpected events are the basis for adaptations of associative strengths and the discrepancy between predicted and actual outcome is directly related to the degree of modification of learned relations (Schultz & Dickinson, 2000; Rescorla & Wagner, 1972).

In implicit learning situations, the person is usually not aware about the constant relations and therefore develops no consciously available predictions about upcoming events. Nevertheless, behavioral measures indicate that the system is able to differentiate between expected and unexpected events even without accompanying awareness. A popular paradigm for investigating implicit sequence knowledge is the serial reaction task (SRTT; Nissen & Bullemer, 1987). In this task, a constant sequence of required motor responses yields a gradual reduction of reaction time (RT) without reliable explicit knowledge about the underlying sequence. When the sequence is changed to a random sequence or a deviant stimulus is introduced in the sequence, a marked increase in RTs is observed (Willingham, 1999; Eimer, Goschke, Schlaghecken, & Stürmer, 1996). The primary causes indicate the detection of a violation of internal expectations. However, the neural basis of this mismatch-detection system that acts without a conscious intention and without conscious awareness is unknown.

In cases where the person is aware of the conflict between expected and actual outcome, a performance monitoring system within the frontal lobe is postulated to detect the processing mismatch. Different aspects of this monitoring system have been examined. In an associative learning paradigm including different levels of unpredictability, the activity in the right dorsolateral prefrontal cortex (DLPFC) was sensitive to the amount of expectancy violation indicating that the DLPFC might play a role in conflict detection (Fletcher, Anderson, et al., 2001). Another brain system involved in cognitive control is the anterior cingulate cortex (ACC), which is activated in response conflicts and error detection (Botvinick, Braver, Barch, Carter, & Cohen, 2001). In response competition where a planned motor response had to be inhibited, activation in the right ventrolateral prefrontal cortex (VLPFC) was reported (Hazeltine, Poldrack, & Gabrieli, 2000; Konishi et al., 1999; Krams, Rushworth, Deiber, Frackowiak, & Passingham, 1998). Activity in the VLPFC was also recruited when stimulus...
contingencies had been changed in a spatial cueing task, resulting in a redirection of attention and response bias (Nobre, Coull, Frith, & Mesulam, 1999). However, in most of the previous experiments, the participants were aware of the incongruent stimulus constellation and the effects within the frontal areas may also be related to a more general conscious evaluation process rather than to distinct cognitive processes such as response inhibition. The aim of the present study was therefore to examine whether frontal systems are also involved in the implicit detection of an expectancy violation when the predictions of upcoming events are not consciously accessible. The advantage of an approach using implicit knowledge is the absence of different processing strategies and evaluation processes that accompany the conscious detection of a prediction error.

In a recent fMRI study (Rose, Haider, Weiller, & Buchel, 2002), we examined implicit learning of constant complex contingencies and demonstrated signal changes within the medial-temporal lobe (MTL) in relation to that learning process. In the “number reduction task” (NRT), participants had to process an eight-digit string in each trial by producing a sequence of seven responses (see Figure 1). All strings were composed of the digits “1,” “4,” and “9.” Participants were instructed to process the strings pairwise from the left to right by two given rules. Unknown to the participants, we embedded a structural contingency (“hidden rule”) in the sequence of responses in each trial. Irrespective of the stimulus pattern, the “hidden rule” was that the response pattern in all trials followed the same underlying principle: The responses for the last three input positions were always the mirror image of the responses for the previous three input positions (in Figure 1: “...9 1 4 4 1 9”). Therefore, Responses 2–4 always determined the last three responses (structured material). The behavioral results clearly demonstrated that the abstract relations between the two input halves were learned in the absence of any explicit knowledge about the “hidden rule.” Learning these constant relations between input halves was accompanied by BOLD signal changes in the MTL. The implicit character of this learning process was demonstrated by postexperimental tests.

In the present study, the identical material was rearranged to result in nondeterminant responses, that is, the final responses (Half 2) were not the mirrored responses from Half 1.

Figure 1. The number reduction task (NRT). Examples of an NRT trial used. The hidden structure used in the previous study ensured that the final three responses were determined by the previous three responses. The mirror symmetry of responses was learned in an implicit way. In the present study, the identical material was rearranged to result in nondeterminant responses, that is, the final responses (Half 2) were not the mirrored responses from Half 1.

Figure 2. Example of a violation trial. After learning the mirror symmetry of responses, in half of the trials the expected last response was replaced by a new response that did not follow the “hidden rule” but was completely correct with regard to the processing rules. Following the “hidden rule,” the last response was determined by the second response, as the fifth and sixth response were determined by the third and fourth responses (dotted lines). The “hidden rule” was violated by replacing the last response so that it was not longer identical to Response 2 (solid lines).
To test for a development of specific expectancies regarding the “hidden rule” in the absence of explicit knowledge, we incorporated a final session where half of the trials violated only the “hidden rule” but not the given processing rules. The violation was restricted to the final input (Figure 2) and resulted in an increase of RTs in comparison to trials without a violation from the same session. The comparison of trials with and without a violation of the “hidden rule” within the last session showed an increase of BOLD signal in the right VLPFC and the MTL for the violated trials. The goal of the present study was to evaluate this violation effect in more detail and to examine which structure is closely related to violation of the expected input. We hypothesized that the increased BOLD signal in the VLPFC and MTL reflected a violation of a learned implicit expectation. Alternatively, the effect may be due to the general novelty of the violated items. Due to the violation of the “hidden rule,” the correct response at the very last position had changed such that the whole response string deviated from the response strings participants had consistently been trained with in previous sessions. The present study was designed to differentiate between both explanations. Participants in the present study received the same amount of training strings. However, in contrast to the previous study, these strings did not follow any “hidden rule,” that is, no contingencies were implemented in the strings (unstructured material). Thus, participants in the current study could not develop any implicit expectancies for certain responses during training, but could develop a general familiarity for response strings repeated during training sessions. In the final session of the present study, we also implemented 50% new response strings, but in contrast to the previous study, no specific expectancies were violated. Again, these strings were created by modifying only the very last position of response strings without changing the sequence of processing rules. Thus, due to the fact that the current response strings did not contain any “hidden rule,” the new strings only differed with respect to the general familiarity, because they were never encountered before. A comparison of the current condition (without a hidden rule) with the condition of the previous study (including a hidden rule) allows for testing the implicit expectation hypothesis against the novelty hypothesis. According to the implicit expectation hypothesis, activity of the right VLPFC results from a violation of an implicit expectation of a specific response. In contrast, the novelty hypothesis holds that the activity of the right VLPFC occurs simply because a novel string occurs and is therefore related to an unspecified detection process of novel stimuli. If the implicit expectation hypothesis is valid, then we should find a smaller effect in the right VLPFC for the last position in the current experiment compared to the violated last position in the previous experiment (which was additionally accompanied by an implicit expectation of a specific response). Such a finding would support the functional role of the right VLPFC for detecting unpredictable events even in implicit learning situations.

A second goal of the present study was to examine the MTL activity previously found in relation to the violation of the “hidden rule” and also in relation to the introduction of the new response strings. In the previous studies (Rose et al., 2002, 2004), we demonstrated MTL involvement during implicit learning. Furthermore, we found effects of the violated trials within the MTL. This effect in the MTL cannot be easily attributed to the violation of implicit expectancies because many functional imaging data implicate the MTL, more precisely the hippocampus, in processing stimulus novelty (Strange & Dolan, 2001; Strange, Fletcher, Henson, Friston, & Dolan, 1999; Dolan & Fletcher, 1997). Therefore, the unfamiliarity of the violated trials in the previous study may account for the effects found in the MTL. However, if the detection of unpredicted events is a necessary mechanism for the adaptation of memory and learning rates, then the MTL effect may also be attributed to the implicit learning rule. The present design also allows for testing the implicit expectation hypothesis against the novelty hypothesis within the MTL. If the MTL is only related to the detection of unfamiliar stimuli, then we should not find any difference between the material with and without the “hidden rule” because both material contain unfamiliar stimuli. However, if the MTL is involved in the implicit learning process of the “hidden rule,” then the expectancy violation should result in an adjustment of the learning rate which should result in an enhanced fMRI signal in the MTL in comparison to the unstructured material.

RESULTS

Behavioral Results
In the postexperimental questionnaire of both experiments, none of the participants reported the presence of an observed regularity or the awareness about the regular repeated input presented in each response string.

Accuracy was calculated for each participant as mean error rate. A two-way ANOVA (factors material and old/new) revealed no difference in error rate between old and new items \(F(1,15) = 0.36, \text{ ns}\) or between material \(F(1,15) = 0.09, \text{ ns}\); interaction \(F(1,15) = 2.1, \text{ ns}\), although in the group with the “hidden rule” a nonsignificant increase in error rate was observed \(t(8) = 1.3, \text{ ns}\).

In the present study, the introduction of new response strings resulted in a small, nonsignificant increase of RT [mean difference of 11 msec, \(t(8) = 0.34, \text{ ns}\)]. A two-way ANOVA (factors material and old/new)
demonstrated a reliable interaction \([F(1,15) = 8.4, p < .05]\) between materials and the introduction of the new trials, indicating that the effect of introducing new trials was reliably larger for the material containing the hidden rule (see Figure 3).

For the last session, we compared fMRI signal of HALF 2 between old response strings (i.e., that have been presented in the previous sessions) and new response strings (i.e., that were modified at the very last position). In the current experiment, the introduction of “new” strings resulted in more BOLD signal than the old strings in the left VLPFC (Figure 4). However, in the regions of the violation effect with the structured material of the previous study (right VLPFC and left MTL structures), this effect was not statistically significant after correction for multiple comparisons (Table 1). More importantly, the group comparison demonstrated a significant difference between material and the introduction of new items (two-way interaction) in the right VLPFC, as well as in the left MTL and the lingual gyrus, indicating a larger difference of BOLD signal for the violated strings of the structured material (Figure 5). No difference between structured and unstructured material was obtained for the left VLPFC. Within the MTL, the effect was dominant in the left posterior hippocampus, but was also present in the right hippocampus, although it failed to reach level of statistical significance.

**Functional Neuroimaging**

*Effects of the Introduction of New Response Strings in the Last Session*

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Table 1. Coordinates (mm) and Magnitudes for the Comparison of New and Old Items

<table>
<thead>
<tr>
<th></th>
<th>Structured Material</th>
<th>Unstructured Material</th>
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<tr>
<td></td>
<td>T</td>
<td>x</td>
</tr>
<tr>
<td>Right VLPFC</td>
<td>4.29**</td>
<td>54</td>
</tr>
<tr>
<td>Left VLPFC</td>
<td>3.41*</td>
<td>-51</td>
</tr>
<tr>
<td>Right MTL</td>
<td>3.12*</td>
<td>27</td>
</tr>
<tr>
<td>Left MTL</td>
<td>4.45**</td>
<td>-39</td>
</tr>
<tr>
<td>Right lingual g.</td>
<td>5.08**</td>
<td>12</td>
</tr>
<tr>
<td>Left lingual g.</td>
<td>4.11**</td>
<td>-24</td>
</tr>
</tbody>
</table>

Group differences (two-way interaction Old/New x Material)

- Right VLPFC: 3.96** 54 39 0
- Left VLPFC: 2.6* 42 42 15
- Right MTL: 2.92* 24 -24 -6
- Left MTL: 4.23** -39 -36 -3
- Right lingual g.: 4.73** 12 -51 -3
- Left lingual g.: 3.81** -24 -54 -6

Effects from the comparison between old and new items within the last session separately for each material (upper section). Group comparison of the new > old contrast (lower section; as a two-way interaction of Material x Old/New).

*Results from the fMRI random effects analysis: \( p < .05 \), uncorrected.

**Results from the fMRI random effects analysis: \( p < .05 \), corrected for multiple comparison with SVC (1000 mm\(^3\)), cluster size > 10 voxels.

**General Differences between Groups**

To control for general differences in the activation levels between groups, we compared effects of HALF 1 within the last session between material. Within the first half of inputs, no new items were introduced and the regularity is also restricted to HALF 2. Therefore, no differences were expected for the BOLD response of HALF 1. In the areas of interest (right VLPFC, MTL), no reliable difference between group even at a very low threshold \( (p < .05, \text{uncorrected}) \) was found. Furthermore, similar main effects of old and new response strings were found for both material (parietal cortex, frontal eye fields, visual areas, VLPFC) (Figure 6).

**DISCUSSION**

The present study demonstrates that implicit learning can result in unconscious expectancies and that violations of these expectancies are detected by neural systems including the right VLPFC and the left MTL. The statistical comparison between material with and without the “hidden rule” shows that reliable effects in these structures and behavioral consequences were specific to the structured material and therefore a direct consequence of the implicit learning process.

Participants were trained for an identical number of trials. The material in each study differed only with respect to the presence or absence of the “hidden rule.” After training, participants received “new” response strings that differed from the training material only at the very last position. For the material with the “hidden rule,” the changed last input position additionally violated implicit expectancies, whereas in the present experiment the modification resulted in unfamiliar response strings only. The behavioral data in the present study showed no evidence for a detection of the novel strings, whereas in the previous study the violation of the “hidden rule” at the last position resulted in a reliable increase of RTs for the violated items. The group comparison showed a reliable difference between task materials. In accordance with the implicit expectation hypothesis, the increase in RT occurred only for the material with the “hidden rule.” This finding contradicts the novelty hypothesis. The behavioral effect of the violation of the learned hidden rule was accompanied by an increase of BOLD signal in the right VLPFC and the left MTL, whereas no significant increase of fMRI signal was observed in the present study for the new response strings in these structures. The introduction of new response strings resulted in an increase of BOLD signal within the left VLPFC for both materials. The group comparison demonstrated that this effect was not different between the structured and unstructured material. Therefore, the introduction of novel items resulted in an increase of BOLD signal in the left VLPFC regardless of the learned hidden rule and might reflect a common effect related to the introduction of unfamiliar,
novel stimuli. However, within the right VLPFC and the left MTL, effects for the new response strings were only found for the structured material (i.e., after implicitly learning the hidden rule). This difference between the material and the introduction of new stimuli was expressed in the corresponding reliable two-way interaction term. The specificity of this effect is further supported by the fact that the group comparison for HALF 1 did not show any differences between material in this areas. This pattern of results suggests that the novelty of items is not sufficient to explain the activation of the right VLPFC and the left MTL as observed with the “structured” material. Rather, it seems that the activation of the right VLPFC and the left MTL depends upon the violation of an expectation, even if the violation was not accessible by conscious awareness.

The absence of awareness for the hidden rule and for the violation of the rule is particularly interesting with respect to the VLPFC activation. In most reported frontal fMRI effects in relation to a prediction error, it is not clear whether the detection process itself or the conscious evaluation of the error is accompanied by frontal activation. Furthermore, the location of the frontal effects varies across studies using different kinds of prediction violation including behavioral errors, omitted rewards, or unexpected stimulus locations (for a review, see Schultz & Dickinson, 2000).

By comparing the two task materials, we argue that the detection of a violation of implicit expectancies results in an activation in the VLPFC. In the violated trials, only one input from the second half did not follow the “hidden rule,” but was completely correct with regard to the given “same–different rule.” This small violation at only a single position resulted in a greater BOLD signal in the right VLPFC for the second half of the violated trials compared to the trials without a violation. This difference demonstrates that the “hidden rule” was learned and that implicit predictions were formed on the basis of that structural regularity and that the violation of the implicit expectancies activated the right VLPFC. Thus, our results are in accord with previous findings that show an increase in VLPFC activation when learned and expected stimulus associations are violated (Nobre et al., 1999) or when response conflicts occur due to other reasons (Hazeltine et al., 2000; Konishi et al., 1999; Krams et al., 1998). However, our results extend these findings by suggesting that the function of

**Figure 5.** Differences between materials. Results of the group comparison of the violation contrast (two-way interaction with factors response strings [new/old] and material [structured/unstructured]). In the right VLPFC and the left MTL, the introduction of new response strings results in a larger effect with the structured material where the new response violated the implicitly learned “hidden rule.”

**Figure 6.** The right VLPFC during training. Activation level for the final half of inputs (mean beta weights) across the five training sessions for both material within the right VLPFC (squares = present study without the hidden rule, circles = old study with the hidden rule). No difference between group was observed during the initial training sessions \[t(15) = 0.5, \text{ns}\].
the VLPFC also holds for learning situations in which the violated expectancy is only implicit and not accessible to conscious awareness. The results therefore indicate that the process of detecting the violation of a predicted event is accompanied by VLPFC effects rather than the conscious evaluation. In a recent fMRI study (Badre & Wagner, 2004), different behavioral control processes have been dissociated within the prefrontal cortex (PFC). Whereas the function of the DLPFC could be attributed selectively to mediating resolution of response conflict, a more ventral and lateral part of the PFC was also engaged by integrating unexpected events into the context during ongoing processing. During a memory task using a list of words, a bias cue predicted a response, but in some trials the response cue violated that prediction. The violation required a modification of the prepared response either by relying on the actual cue or by using the memory information. Whereas DLPFC regions were selectively engaged by modifications of the predicted response, the bilateral ventral PFC was additionally engaged by the integration of memory information. This suggests an integrative function of the VLPFC and is in accord with our results that demonstrate an important role of the VLPFC in the detection of unexpected events during learning.

Previous imaging studies using the SRTT (Peigneux et al., 2000; Hazeltine, Grafton, & Ivry, 1997; Grafton, Hazeltine, & Ivry, 1995; Rauch et al., 1995) presented training blocks with random sequences to assess the degree of implicit learning and as a baseline condition to evaluate brain regions involved in implicit learning the constant motor sequences. To our knowledge, none of these studies examined the physiological basis of single violations of implicit expectancies. Our study revealed areas that are engaged by the detection of violated implicit expectancies and these areas are different from that engaged during learning the constant relations. Whereas implicit learning of the hidden rule was accompanied by modulations of MTL activation, the right VLPFC was selectively engaged by the occurrence of unexpected events that deviated from the hidden rule. The fact that the unpredictable events also resulted in effects within the left MTL shows the affiliation of this process to the associative learning mechanism. This is in accord with a distinct learning procedure related to the modification of learning rate based on the comparison of expected and actual outcome (Roscicola & Wagner, 1972).

In previous functional imaging studies on memory, the right VLPFC was often found to be engaged in the maintenance of spatial information and the left VLPFC in the maintenance of verbal information (for a review, see Fletcher & Henson, 2001). The spatial character of the “hidden rule” of the NRT might therefore be related to a larger effect in the right VLPFC.

A further interesting finding is the absence of effects within the ACC, although expected on the basis of performance monitoring and cognitive control (Botvinick, Braver, et al., 2001; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter et al., 1998). However, a recent fMRI study (Dehaene et al., 2003) using masked and unmasked stimuli demonstrated ACC effects only in situations in which the conflict was available to conscious awareness. In accordance with our results, the authors argue that subliminal conflicts are resolved without ACC contribution. As for the VLPFC, the comparison between the two task materials clearly shows that the novelty of the new response strings is not sufficient to explain activation of the MTL. The effect was reliably larger if the new responses violated the learned relations between inputs given by the “hidden rule.” Implicitly learning constant relations was accompanied by increasing BOLD signals within the ventral perirhinal cortex (Rose et al., 2002). However, the violation effect of the implicit predictions can be isolated by the group comparison of the present examination and was located in the posterior hippocampus. The function of the hippocampus has been attributed mainly to memory (e.g., Eichenbaum, 1999; Squire & Zola-Morgan, 1991) and novelty processing (Strange & Dolan, 2001). By segregating the novelty effects within the hippocampus, it was demonstrated that the posterior part encodes familiarity of stimuli that have a behavioral relevance (e.g., exemplar familiarity) (Strange, Fletcher, et al., 1999). In accord with theories of learning (Roscicola & Wagner, 1972), the involvement of the MTL in the present experiment may therefore indicate the adaptation of memory and learning rates on the basis of unpredictable events.

In summary, the present results suggest that an unconsciously detected discrepancy between predicted and actual outcome recruits the right VLPFC and results in a modification of learned relations within the left MTL.

METHODS

Participants
A total of 18 volunteers participated in both experiments. Eight healthy volunteers (mean age 23 years, range 22–26 years, 5 women) participated in the present study using the unstructured material and 10 healthy subjects (mean age 26 years, range 22–39 years, 5 women) participated in the previous study with the material structured by the “hidden rule.” All subjects were right-handed, and had normal or corrected-to-normal vision. The study was approved by the local ethics committee and all participants gave written informed consent prior to participating in the study.

Stimuli
Digit strings were presented in white on a gray background controlled by a PC that ensured synchronization.
with the MR-scanner using the software “Presentation” (http://nbs.neuro-bs.com). An LCD projector projected the stimuli on a screen positioned on top of the head coil, which was viewed by the subjects through a mirror (10° × 15° field of view). Participants entered the responses by pressing buttons on an MR-compatible device.

Procedure

In each trial, a string of eight digits was presented on the screen (Figure 1). All strings were composed of three different digits (“1,” “4,” and “9”). Participants were asked to process the stimuli pairwise from left to right by applying the “same–different rules.” The “same rule” states that two identical digits require responding with the digit itself (i.e., “4” “4” results in “4”). The “different rule” states that two different digits require responding with the remaining third digit (i.e., “1” “4” results in “9”). First, the two leftmost digits of a given string are processed (in the example in Figure 1, the digits “1” and “9”). According to the “different rule,” two different digits require responding with the remaining digit, the first pair provides “4” as the result. After 1.6 sec, the correct result was displayed below the third digit. However, the task of the participants was to respond before the result appeared. All remaining comparisons are made between the preceding result and the next digit in the digit sequence; that is, the result of the first comparison, “4” is compared with the digit “1,” the next digit in the digit sequence (position three). The result of this comparison is, according to the “different rule,” “9.” Next, this result, (i.e., the digit “9”) is compared to the next digit in the string, a “4.” Comparing the digits “9” and “4” results, again according to the different rule, in a “1.” On any given trial, participants entered a total of seven responses. The application of the “same–different rules” was identical in both studies.

In the previous study, we incorporated an invariant in every response string of the first five learning sessions. The digit strings were constructed with a “hidden structure” in the response pattern of the form “x a b c c b a” (“x,” “a,” “b,” and “c” representing the digits “1,” “4,” or “9”). Thus, the last three responses were always the mirrored image of the responses at Positions 2–4. It is important to note that the regularity in the response pattern does not correspond with any overt structure in the presented stimulus string. For example, the digit strings “1 4 1 9 4 9 4 9” and “1 4 4 4 4 1 4 4” both result in a response string that followed the “hidden rule” (i.e., “9 4 1 9 9 1 4” and “9 1 9 1 1 9 1”) but do not share any other structural characteristic. An important feature is that due to the “hidden rule,” in each trial the first half of inputs is not determined, whereas the second half of inputs can be predicted by previous responses. Therefore, the last input was determined by the input at the second position in the response string. The participants received no information about the underlying principle in construction of the strings.

To prevent participants from developing distinct expectancies regarding structural characteristics in the current study, the same material was rearranged to form new strings without the “hidden rule.” In this new material, the last responses were not determined by previous inputs but the response strings matched the other characteristics of the structured material. The number of “same-rule” and “different-rule” applications and the digits used as final results were identical in both materials. Due to the symmetry of the “hidden rule,” all strings in the previous study contained a repeated input (Figure 2). To obtain comparable material for the present study, we also included a repeated input in all response strings. All experimental conditions such as instruction and training remained constant across both studies. Across the five training sessions, each response string was repeated five times to ensure an identical degree of familiarity for each string. Therefore, the only difference between both studies was the presence or absence of the “hidden rule” that determined the last three inputs in the previous study.

The aim of the present experiment was to test the implicit expectation hypothesis against the novelty hypothesis. In the previous study, half of the trials in Session 6 (40 trials total) deviated from the “hidden rule” at the last position. Thus, the last response was no longer determined by the response for Input Position 2 (e.g., if “4 9 1 4 4 1 9” was the original response pattern, the new pattern was “4 9 1 4 1 4 4”). Although this resulted in a violation of the “hidden rule,” the response was always in accord with the “same–different rules.” In addition to violating the “hidden rule,” the altered response strings can be described as “new” because they have not been encountered before. In this study, we presented “new” response strings without a violation of a “hidden rule” (as there was no hidden rule embedded in the training material). Analogous to the previous study, new response strings were created for the “unstructured material” by replacing only the very last input of the original response strings without altering the “same–different rule” sequence of the original strings. That is, the processing rule at the last positions never changed (always, the “different rule” had to be applied). In Session 6, half of the trials were drawn from this new trial list and half of the trials from the original training list. In both studies, each of the new trials was repeated only once to prevent familiarity effects for this trials.

Reaction times and accuracy were assessed for all inputs. Comparisons were made between the old and new trials of the sixth session and between groups (“structured” and “unstructured” material).
For the structured material in the previous study, we tested for the absence of explicit knowledge and excluded one participant that demonstrated explicit memory regarding the “hidden rule.” For the unstructured material in the present study, the participants only had to rate the presence of a regularity and were asked whether they detected that in each trial there was a double input.

Design
Each trial consisted of the processing of an eight-digit string which requires the calculation of seven responses. As in the previous study, the time limit for each input was 1.6 sec resulting in a trial duration of 11.2 sec (7 × 1.6 sec). The length of the intertrial interval (ITI) with a fixation cross on the screen was randomized between 2 and 10 sec and served as a baseline condition. For each of the first five sessions, 30 digit strings were randomly chosen from the list of the “unstructured material” (duration about 9 min per session). Each session was followed by a rest period of 5 min. The sixth session was slightly longer and consisted of 20 trials from the original list and 20 digit strings that differed at the last response position.

fMRI Methods
Functional MRI was performed on a 1.5-T system (Siemens Vision, Munich, Germany) with a gradient-echo EPI T$_2^*$-sensitive sequence in 32 contiguous axial slices (3 mm thickness with 1 mm gap, TR 2.6 sec, TE 40 msec, flip angle 90°, field of view 210 × 210 mm$^2$, matrix 64 × 64). For display purposes, a high-resolution (1 × 1 × 1 mm voxel size) structural MRI was acquired for each participant using a standard 3-D T$_1$-weighted FLASH sequence.

Image processing and statistical analysis were carried out using SPM99 (www.fil.ion.ucl.ac.uk/spm). All volumes were realigned to the first volume, spatially normalized to a standard EPI template (SPM99), and smoothed using a 10-mm full width at half maximum (FWHM) isotropic Gaussian kernel. The structural volume was coregistered to the functional scans by normalizing it to a T$_1$-weighted template in the same space as the template used to normalize the functional dataset.

As in the study with the structured material, data analysis was performed by modeling the first and the second half of the responses as boxcar functions with variable duration convolved with a hemodynamic response function. The duration was computed using the individual processing times in the first and the second half of each trial. This was conducted separately for the regular trials and the new trials in the sixth session of both materials. An additional regressor was created for the error trials modeling the whole trial as a regressor with fixed duration (11 sec) (resulting in five regressors for each material: old HALF 1, old HALF 2, new HALF 1, new HALF 2, and error trials). Regression coefficients for all regressors were estimated using least squares within SPM99 (Friston et al., 1995). A high-pass filter with a cutoff period of 120 sec and a low-pass filter (Gaussian envelop FWHM of 4 sec) were used.

To test for the effect of the violation of the “hidden rule” and the introduction of new response strings, we estimated identical contrasts and compared the second half of inputs between regular and new trials for both materials. Second-level analyses were performed independently for each group and also as a between-group comparison. The threshold adopted was $p < .05$.

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The data reported in this experiment have been deposited in the MRI Data Center (www.fmridc.org). The accession number is 2-2005-118G7.

REFERENCES


