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When obvious covariations are not even learned implicitly

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The present experiments examine the impact of covariation type and attention on implicit covariation learning. Experiments 1 and 2 compare learning of stimulus–stimulus (s–s) and stimulus–response (s–r) covariations. Although stimuli and responses were predicted by a distinct feature of the display, implicit learning neither of s–s nor of s–r covariations was observed. Experiments 3–5 explore the impact of attention on implicit learning of an s–r covariation. Distinct features either of the targets or of an incidental but centrally presented object predicted the responses. Implicit covariation learning was restricted to predictors that were part of to-be-attended targets. Finally, Experiment 6 shows implicit learning of a partial s–r covariation in which only one of two responses is predicted by target features. It is argued that implicit learning is based on the formation of associations between simultaneously activated distinct representations. Because only attended stimuli seem to reach a sufficient level of mental distinctiveness, attending the predictive information most likely is an indispensable prerequisite for implicit covariation learning to occur.

Covariations between successive events allow to predict and to prepare for what will happen. Consequently, organisms respond faster and more appropriately to predicted than to unpredicted events. As faster responding supports survival, it is reasonable to assume that evolution afforded mechanisms by which organisms automatically adapt to covariations. These supposed mechanisms are commonly referred to as ''implicit learning''. For example, Reber (1989, p. 233) characterised implicit learning as ''a general, modality free Urprocess, a fundamental operation whereby critical covariations in the stimulus environment are picked up''.

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Implicit covariation learning has been demonstrated in various experimental settings: For example, while memorising letter strings, participants incidentally adapt to grammatical structures they are unable to report (e.g., Gomez & Schvaneveldt, 1994; Reber, 1967, 1989). In serial reaction time (SRT) experiments, participants respond increasingly faster to structured stimulus sequences than to random sequences although they cannot report any of the serial constraints (e.g., Cohen, Ivry, & Keele, 1990; Hoffmann & Koch, 1998; Koch & Hoffmann, 2000; Nissen & Bullemer, 1987). Likewise, in visual search tasks, targets are detected faster if features of the search display point to target locations, even though participants do not notice the feature-location covariation (Chun & Jiang, 1998; Hoffmann & Kunde, 1999; Lambert, Naikar, McLachlan, & Aitken, 1999; Lewicki, 1986a).

However, participants often failed to adapt to covariations they did not notice (Hendrickx, de Houwer, Baeyens, Eelen, & van Avermaet, 1997a; Hoffmann, Martin, & Schilling, 2003; Jiang & Chun, 2001; Jiménez & Méndez, 1999; Willingham, Nissen, & Bullemer, 1989; Wolff & Rübeling, 1994). In particular, Hendrickx et al. (1997a) reported a series of 12 carefully designed experiments in which participants were exposed to various stimulus covariations but the data of only one of the experiments indicated implicit learning. These failures to demonstrate implicit learning suggest that participants do not adapt to every covariation in the environment. Rather, certain conditions seem to be required for implicit covariation learning to occur (cf. Hendrickx, de Houwer, Baeyens, Eelen, & van Avermaet, 1997b; Lewicki, Hill, & Czyzewska, 1997).

The present experiments were designed to contribute to the exploration of conditions that may influence the occurrence of implicit covariation learning. The first two experiments deal with the type of the covariation to be learned. In particular, implicit learning of covariations between stimuli is compared with implicit learning of covariations between stimuli and required responses. Experiments 3–5 explore the impact attention has on implicit learning of a stimulus response covariation. Finally, Experiment 6 examines whether implicit learning requires a true covariation between two variables or whether coactivations of stimuli and responses suffice for the corresponding representations to become connected.

EXPERIMENT 1

Previous research on implicit covariation learning has explored diverse types of covariations which can be roughly classified as stimulus–stimulus (s–s) or stimulus–response covariations (s–r). A typical s–s covariation comprises an incidental feature predicting another feature that also is response-irrelevant in the learning phase as, for example, the layout of a search display predicting the location of the target (Chun & Jiang, 1998; Hoffmann & Kunde, 1999) or hair length predicting the kindness of a person (Hendrickx et al., 1997a; Lewicki, 1986a). In contrast, in s–r covariations, an incidental stimulus predicts the *imperative* stimulus and in turn the required response in the learning phase. For example, an irrelevant tone predicts the response-relevant category of a subsequently presented word (Hendrickx et al., 1997a), or the irrelevant shape of a stimulus predicts the response-relevant location of the next stimulus (Jiménez & Méndez, 1999).

S–s and s–r covariations differ with respect to the benefits they provide. S–s covariations allow for a facilitation of stimulus processing only. In contrast, s–r covariations additionally allow for response preparation. Accordingly, it can be suspected that s–r learning might be privileged in comparison to s–s learning (cf. Hoffmann et al., 2003). Although there are studies both showing (e.g., Chun & Jiang, 1998; Lewicki, 1986a) and failing to show (Hendrickx et al., 1997a; Jiang, & Chun, 2001) implicit learning of both types of covariations, a direct comparison of implicit learning of s–s and s–r covariations is still missing. Experiment 1 was designed for such a comparison.

Participants performed a visual search task. A task-irrelevant feature of the search display, the cue, covaried with either the identity or the location of the target. Half of the participants were to respond to the identity of the target and the other half were to respond to its location. Therefore, when participants responded to target location, the cue-location covariation did not only allow for a prediction of target locations but also of the required responses. Likewise, when participants responded to target identity, the cue-identity covariation did not only allow for a prediction of the forthcoming target but also for a preparation of the forthcoming response. The respective other participants, however, merely experienced s–s covariations. Thus, the orthogonal combination of two imperative features (identity vs. location) with two different covariations (cue-identity vs. cue-location) allows for a direct comparison of learning s–s and s–r covariations under otherwise identical conditions.

Method

Task and apparatus. Stimuli were presented on a 15-inch VGA monitor in colour on a green background and were viewed from a distance of about 60 cm. In each trial, two decks of cards were presented in the upper left corner of the screen with either fish or palms on the backs. After a short delay, three by three cards were distributed with their backs facing up, either from the deck with fish or with palms. Each individual card was 36 mm in height and 26 mm in width and the 3 by 3 individual cards covered an area of 120 mm by 120 mm approximately in the centre of the screen. Then, only the cards at the four corners were turned up so that their pictures became visible whereas the backs of the other five cards remained facing up (cf. Figure 1). There was always either a 7 of spades or a 6 of hearts amongst the upturned cards. Participants were requested to search for these two targets and to respond to the current target as

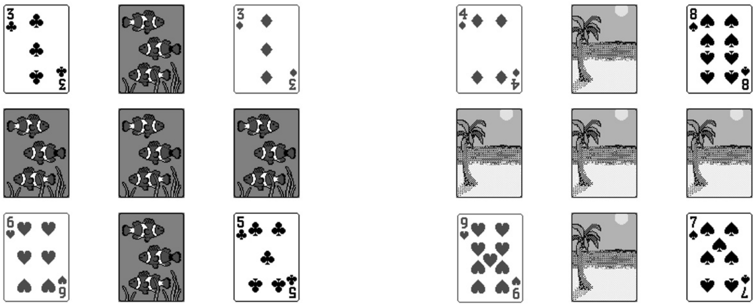

Figure 1. Illustration of the displays used in Experiment 1. Participants searched for two target cards. The symbols on the card backs (fish or palms) reliably predicted the identity or the location of the target to either of which participants responded.

quickly and correctly as possible. The three distractors were selected from all cards of an ordinary pack with the values 2–9, including the 7 of clubs, the 6 of diamonds, the 7 of hearts, and the 6 of spades. Selection was random except that always two black (clubs or spades) and two red suits (hearts or diamonds) were presented. Thus, identifying the targets required the consideration of both, the critical value and the critical suit of the targets (conjunction search).

The two cursor keys ‘‘left’’ and ‘‘right’’ in the bottom row of a standard computer keyboard served as response keys. The keys were to be pressed with the index fingers of the left and the right hand.

Design. The first experimental variable concerned the covariation between the symbols on the card backs (fish vs. palms) and target features. For half of the participants the symbols covaried with the identity of the targets, that is, fish always cooccurred with the 6 of hearts and palms always cooccurred with the 7 of spades (or vice versa), the locations of the targets being random. For the other half of participants, the symbols covaried with the location of the target, that is, the target was always presented on the left side of the matrix with fish and it was always presented on the right side with palms on the card backs (or vice versa). In this case the identity of the targets was random. The second experimental variable concerned the imperative target feature. Half of the participants were to respond to the identity of the target, that is the 6 of hearts called for pressing the left key and the 7 of spades for pressing the right key (or vice versa). The other half of participants were to respond to the location of the target. The left key was to be pressed when targets were presented on the left, and the right key was to be pressed when targets were presented on the right side of the card matrix. An orthogonal combination of both variables resulted into four groups: $_{\text{pred}}\text{LL}_{\text{rel}}$, $_{\text{pred}}\text{LI}_{\text{rel}}$, $_{\text{pred}}\text{IL}_{\text{rel}}$, and $_{\text{pred}}\text{II}_{\text{rel}}$. The first letter refers to the target feature that covaried with the card backs and which was therefore predicted ($_{\text{pred}}\text{L}$ = location vs. $_{\text{pred}}$I = identity). The second letter refers to the relevant response feature (L$_{\text{rel}}$ = location vs. I$_{\text{rel}}$ = identity). Groups $_{\text{pred}}$LL$_{\text{rel}}$ and $_{\text{pred}}$II$_{\text{rel}}$ experience stimulus–*response* covariations as card backs not only allowed for the prediction of either the location or the identity of the target but additionally for a prediction of the required response. In contrast, groups $_{\text{pred}}$LI$_{\text{rel}}$ and $_{\text{pred}}$IL$_{\text{rel}}$ merely experience stimulus–s*timulus* covariations: The card backs again allow for predicting either the location or the identity of the target but not for predicting the required response. Thus, the design explores learning s–s and s–r covariations under otherwise identical conditions.

The experiment was run in 12 blocks of 50 trials each. In each trial one of the two symbols on card backs was randomly selected. In Blocks 1–10 and in Block 12 the card backs covaried with either the location of the target or with its identity as described. The mappings of the targets (6 of hearts vs. 7 of spades) as well as of their locations (left vs. right) to the backs (fish vs. palms) were balanced between participants. In Block 11, the covariation was abolished in all four groups, that is targets and their locations were both randomly selected irrespective of the current symbol on the card backs.

Procedure. The instruction explicitly stated that there were two different decks with either fish or palms on the backs and that from any of the two decks three by three cards would be selected. Flipping of the four cards and the respective assignment of the responses to the targets or their locations were explained and participants were asked to respond as quickly and as accurately as possible. The index fingers of both hands were to rest on the response keys. Each trial started with the presentation of the two decks. After 100 ms the three by three cards were distributed and after another delay of 1000 ms the four cards at the corners were turned up. The target, the three distractors, and the predictive card backs of the other five cards remained on the screen until the response was registered. The latency between turning the cards and the response was measured as reaction time (RT) in milliseconds. Erroneous responses were fed back by a short noise and the next trial started 1000 ms after each response. At the end of each block, participants were informed about mean RT and error rate of the last block and they were asked to further improve their performance.

At the end of the experiment, awareness of the covariation was explored in a standardised interview. First, participants were asked whether they had used any strategy in order to respond fast. Second, they were asked whether they had noticed anything special. Finally, they were told that the trials with fish and palms on card backs were different and asked to state what this difference might have been. If the answers contained no hint at all that the covariation had been noticed, the respective participant was considered as being unaware of the covariation. The total time to complete the experiment was approximately 45 minutes.

Participants. Sixty-four students of the University of Würzburg participated in the experiment. There were 54 female and 10 male participants. The mean age was 22.44 years (*SD* = 3.74). Sixteen participants each were randomly assigned to the four groups, ${}_{\text{pred}}\text{LL}_{\text{rel}}$, ${}_{\text{pred}}\text{LI}_{\text{rel}}$, ${}_{\text{pred}}\text{IL}_{\text{rel}}$, and ${}_{\text{pred}}\text{II}_{\text{rel}}$.

Results

Exploratory analyses

According to the postexperimental interview, a minority of 13 participants became aware of the covariations: There were 3, 2, and 8 aware participants in groups ${}_{\text{pred}}\text{LL}_{\text{rel}}$, ${}_{\text{pred}}\text{LI}_{\text{rel}}$, and ${}_{\text{pred}}\text{II}_{\text{rel}}$, respectively. None of the participants in group ${}_{\text{pred}}\text{IL}_{\text{rel}}$ detected that the fish and palms systematically cooccurred with one of the two targets, respectively. Altogether, 51 participants were classified as being unaware.

RTs and accuracy data

RTs longer than 3000 ms (0.3%, 0.2%, 0.2%, and 0.2%) as well as RTs from error trials were discarded from the analysis (4.4%, 3.9%, 6.4%, and 3.1%, in groups ${}_{\text{pred}}\text{LL}_{\text{rel}}$, ${}_{\text{pred}}\text{LI}_{\text{rel}}$, ${}_{\text{pred}}\text{IL}_{\text{rel}}$, and ${}_{\text{pred}}\text{II}_{\text{rel}}$, respectively). For each participant, the mean RTs of the remaining responses and the error rates of each block were calculated. Figure 2 shows the mean RTs plotted over blocks separately for participants classified as being aware or unaware in each group.

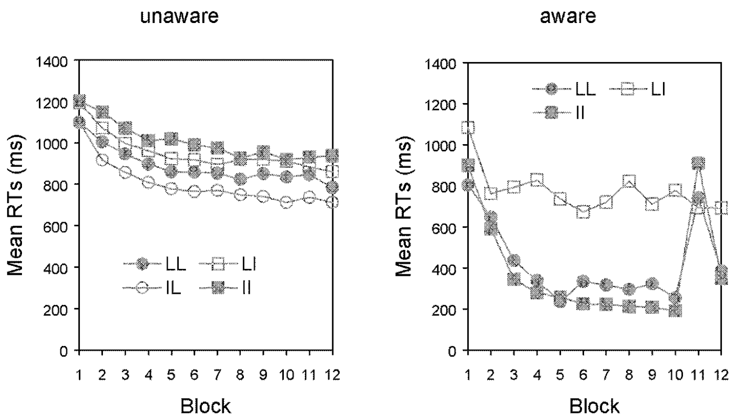

Figure 2. Mean RTs of participants in Experiment 1 who were either aware or unaware of a predictive covariation under four different conditions LL, LI, IL, and II. The first letter denotes the predicted target feature and the second letter denotes the imperative target feature (L = location, I = identity). In Block 11 the covariation was abolished.

Aware participants. As there were only a few ''aware'' participants, no statistical analyses could be performed on their data that are therefore discussed with caution. If card backs reliably predicted the required response (groups $_{\text{pred}}\text{LL}_{\text{rel}}$ and $_{\text{pred}}\text{II}_{\text{rel}}$), the aware participants obviously profited from the covariation. Mean RTs decreased to about 250 ms in Block 10 and increased up to the level of the first block in Block 11. In contrast, the data of the two aware participants in group $_{\text{pred}}\text{LI}_{\text{rel}}$ did not indicate any use of the detected predictability of target locations. Both participants declared that they did not rely on the predictive relation as it took too much effort, first, to predict the target location (left or right) and to decide between a left and a right response immediately afterwards (cf. Carlson & Flowers, 1996, for similar observations).

Unaware participants. In order to assess implicit effects of the covariations, the mean RTs and error rates of Blocks 10 and 11 were subjected to an analysis of variance (ANOVA) with repeated measures on Block (10 vs. 11) and imperative feature (location vs. identity) and response prediction (predicted vs. nonpredicted) as between-subject factors. If the covariations did have any impact on behaviour, RTs and error rates should increase in Block 11 in which the covariations were abolished.

The ANOVA on the RT data revealed as the only significant effect an impact of imperative feature on RTs, $F(1, 47) = 7.482$, $p = .009$, $\eta^2 = .137$. Participants responded faster to target locations than to target identities (782 ms vs. 911 ms). The critical block effect, $F(1, 47) < 1$, $\eta^2 = .005$, as well as the interactions between block and imperative feature, $F(1, 47) = 1.407$, $p = .242$, $\eta^2 = .029$, and between block and response prediction, $F(1, 47) < 1$, $\eta^2 = .009$, failed to reach significance.

A corresponding ANOVA on the error rates of Blocks 10 and 11 confirmed the RT analyses: The only effect which approached significance was again the impact of imperative feature, $F(1, 47) = 3.965$, $p = .052$, $\eta^2 = .078$: Responses to target locations were more error prone than responses to target identities (5.45% vs. 3.27%), indicating a speed–accuracy tradeoff: Participants responded faster to target locations than to target identities but tended to accept more errors. The critical block effect was far from being significant, $F(1, 47) < 1$, $\eta^2 = .003$. All other effects also failed to reach significance (all p's > .2).

In order to refine our evaluation, we analysed the data of Block 11 in more detail. As in Block 11 the covariations between card backs and either the identities or the locations of the targets were replaced by random mappings, about half of the trials corresponded (''old'') or did not correspond (''new'') to the mappings experienced in the 10 previous blocks. For example, if in Blocks 1–10 fish always cooccurred with a 6 of hearts and palms always with a 7 of spades ($_{\text{pred}}\text{I}$), in Block 11 these ''old'' mappings randomly alternated with ''new'' ones in which fish cooccurred with a 7 of spades and palms with a 6 of hearts, mappings that participants had never experienced previously in the blocks. If the covariations did have any impact on behaviour, RTs and error rates should be increased for the ‘‘new’’ mappings in comparison to the ‘‘old’’ ones.

A corresponding ANOVA over the mean RTs with repeated measures on mapping (old vs. new) and imperative feature and response prediction as between-subject factors revealed only two significant effects: First, participants responded faster to target locations than to target identities, $F(1, 47) = 5.647$, $p = .022$, $\eta^2 = .107$; 791 ms vs. 905 ms. Second, there was a significant triple interaction between mapping, imperative feature, and response prediction, $F(1, 47) = 5.247$, $p = .027$, $\eta^2 = .100$: When responses were predicted, participants responded faster to old in comparison to new mappings when location was relevant (836 ms vs. 858 ms), but more slowly when the identity of the target was relevant (947 ms vs. 912 ms). In contrast, if card backs did not predict the response, these relations were reversed. Now, in old compared to new mappings, responses were somewhat slower to locations (741 ms vs. 728 ms) but somewhat faster to identities (871 ms vs. 890 ms). As this triple interaction was not replicated in Experiment 2 and as we do not see any reasonable account for this result, we consider it as accidental. The critical main effect of mapping, $F(1, 47) < 1$, $\eta^2 = .001$, as well as the interactions of mapping with imperative feature and response prediction were far from being significant (both F’s < 1).

The corresponding ANOVA on the error rates of old and new mappings in Block 11 yielded no significant mapping effect, $F(1, 47) = 1.093$, $p = .301$, $\eta^2 = .023$, no significant interactions with mapping (all F’s < 1), and no other significant effect (all p’s > .18).

Discussion

Experiment 1 aimed at a comparison between implicit learning of s–s and s–r covariations under otherwise identical conditions. The data show that the same s–s covariations are more likely to be consciously detected if they additionally allow a prediction of the responses: In the groups in which an s–r covariation was employed, 11 of 32 participants were classified as being aware whereas only 2 of 32 participants reported to have recognised the corresponding s–s covariations, $\chi^2(1) = 7.69$, $p < .01$. However, there were no differences regarding implicit learning. The data provide no reliable indication that participants adapt to either s–s or s–r covariations without detecting them. Apparently, the present s–r as well as s–s covariations exert no reliable influence on performance unless they are detected.[1]

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[1] In drawing conclusions from null results, statistical power is a crucial issue (Cohen, 1988). In order to address this issue, we performed a power calculation according to the program GPOWER provided by Erdfelder, Faul, and Buchner (1996). Acting on the assumption that implicit learning would result into large effects (cf. Hendrickx et al., 1997a, p. 216), the obtained power value is 0.9853. Even for a medium effect the power value is still acceptable (0.7731). Thus it seems unlikely that the failure to find implicit learning effects is due to a lack of statistical power.

As mentioned in the introduction, several studies have already failed to show implicit covariation learning. However, in these studies the predictive information was often a tiny and hidden detail as, for example, the pitch of the fourth tone in a series of seven tones (Hendrickx et al., 1997a, Exp. 5). Other studies employed complex and probabilistic covariations as, for example, four shapes predicting four stimulus locations with a probability of .80 (Jiménez & Méndez, 1999; cf. also Jiang & Chun, 2001). Also simple deterministic covariations failed to show implicit learning. For example, a covariation between the direction of gaze (left vs. right) and the age (old vs. young) of human faces, presented on photographs, exerted no influence on subsequent age estimations (Hendrickx et al., 1997a, Exps. 7–9). In these experiments, however, participants saw only 10 faces with the critical covariation, which may have been too little to bring about an effect.

In the present study, the predictive stimulus was neither a tiny detail nor was the covariation complex and probabilistic, nor did participants have insufficient opportunity to experience the covariation. On the contrary, the predictive fish and palms were a central feature of the display, the covariations were deterministic and simple, and participants had ample opportunity to experience the covariations. Nevertheless, without conscious detection, the employed s–s and s–r covariations exerted no reliable influence on performance. Thus, neither lack of conspicuity of the predictive information nor insufficient strength of the covariation nor insufficient training seem to be responsible for failures to learn s–s as well as s–r covariations.

EXPERIMENT 2

The failure to find implicit covariation learning in Experiment 1 might be due to a deficient processing of the predictors. As the predictive fish and palms on card backs were irrelevant to accomplish the required visual search, they were possibly not distinctively enough encoded by the ‘‘unaware’’ participants in order to enter individual associations. Verbal learning research has frequently demonstrated that nonfunctional stimuli were neither recalled nor did they become involved in associative connections (e.g., James & Greeno, 1967; Postman & Greenbloom, 1967; Underwood, Ham, & Ekstrand, 1962). This research also showed that the formation of associations to task-irrelevant information is facilitated when familiar stimuli are concerned (e.g., Cohen & Musgrave, 1964; Musen, Szerlip, & Szerlip, 1999). Thus, in order to ensure that the predictive card backs evoke distinctive representations, the fish and palms on card backs were replaced by the capital letters A and B in Experiment 2 (cf. Figure 3). It should be difficult not to encode these intrusively presented A’s and B’s. Accordingly, we not only expected a higher portion of participants to become aware of the covariations but also implicit effects on the behaviour of participants who may remain unaware of the covariations.

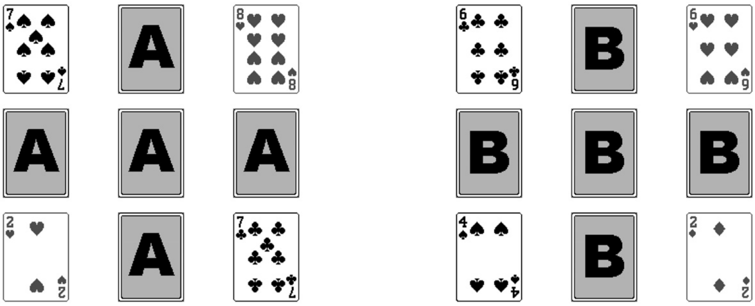

Figure 3. Illustration of the displays used in Experiment 2. Participants searched for two target cards. The symbols on the card backs (A's or B's) reliably predicted the identity or the location of the target to either of which participants responded.

Method

All conditions of Experiment 1 were replicated except that the fish and palms on card backs were replaced by the capital letters A and B.

Participants. Thirty-two students of the University of Würzburg participated in the experiment. There were 28 female and 4 male participants. The mean age was 21.56 years (*SD* = 3.89). Eight participants each were randomly assigned to the four groups, $_{\text{pred}}\text{LL}_{\text{rel}}$, $_{\text{pred}}\text{LI}_{\text{rel}}$, $_{\text{pred}}\text{IL}_{\text{rel}}$, and $_{\text{pred}}\text{II}_{\text{rel}}$, respectively.

Results

Exploratory analyses

According to the postexperimental interview, 21 participants were classified as being unaware. Only a minority of 11 participants became aware of the experienced covariations. There were 3, 1, 3, and 4 ''aware'' participants in groups $_{\text{pred}}\text{LL}_{\text{rel}}$, $_{\text{pred}}\text{LI}_{\text{rel}}$, $_{\text{pred}}\text{IL}_{\text{rel}}$, and $_{\text{pred}}\text{II}_{\text{rel}}$, respectively. In comparison to Experiment 1, in which about 20% of the participants were classified as being aware, the rate of ''aware'' participants increased to 34%.

RTs and accuracy data

RTs longer than 3000 ms (< 0.1%, 0.2%, 0.4%, and 0.2%) as well as RTs from error trials were discarded from the analysis (3.1%, 3.5%, 7.9%, and 3.1% in groups $_{\text{pred}}\text{LL}_{\text{rel}}$, $_{\text{pred}}\text{LI}_{\text{rel}}$, $_{\text{pred}}\text{IL}_{\text{rel}}$, and $_{\text{pred}}\text{II}_{\text{rel}}$, respectively). For each participant, the mean RTs of the remaining responses and the error rates of each block were calculated. Figure 4 shows the mean RTs plotted over blocks separately for participants classified as being aware and unaware in each group.

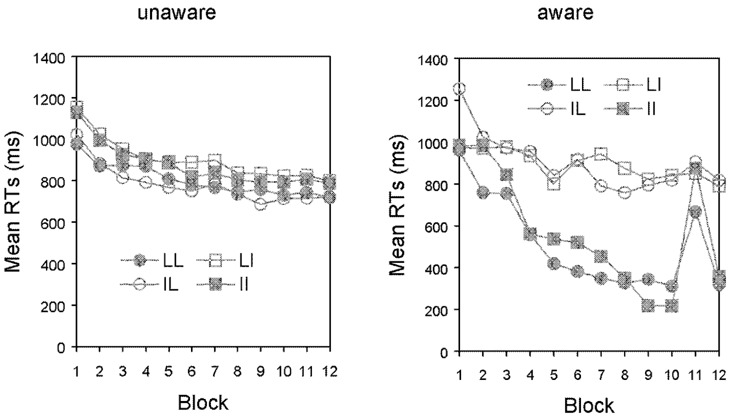

Figure 4. Mean RTs of participants in Experiment 2 who were either aware or unaware of a predictive covariation under four different conditions LL, LI, IL, and II. The first letter denotes the predicted target feature and the second letter denotes the imperative target feature (L = location, I = identity). In Block 11 the covariation was abolished.

Aware participants. Because of the the small number of ''aware'' participants we did not conduct a statistical analysis of their data that are therefore discussed with caution. When the card backs predicted the required response, the seven ''aware'' participants obviously profited from the covariation. The mean RTs decreased continuously until Block 10 and substantially increased again in Block 11. When only the location or the identity of the target but not the required response was predicted, the data of the four ''aware'' participants did not indicate a systematic use of the detected covariations. As in Experiment 1, the participants declared that it took too much effort to intentionally predict the location or the identity of the target, so that they mostly omitted predicting.

Unaware participants. We conducted the same ANOVAs as for Experiment 1. The ANOVA on the mean RTs of Blocks 10 and 11 revealed no significant effects. Participants again responded faster to target locations than to target identities (726 ms vs. 812 ms) but the effect failed to reach significance, $F(1, 17) = 2.357$, $p = .143$, $\eta^2 = .122$. The critical block effect was far from being significant, $F(1, 17) < 1$, $\eta^2 = .028$, as were all interactions with block (all F's < 1).

The ANOVA on the error rates of Blocks 10 and 11 revealed an impact of response prediction as the only significant effect, $F(1, 17) = 6.666$, $p = .019$, $\eta^2 = .282$. Participants performed fewer errors when the card backs predicted the responses (2.48%) compared to the responses that were not predicted (6.07%). This effect, however, is most probably due to group differences instead to response prediction, as abolishing the predictions in Block 11 did not result into an increase but into a decrease of error rates, which was only marginal when responses were predicted (2.5% to 2.45%) but substantial when responses were not predicted (6.97% to 5.17%), $F(1, 17) = 3.578$, $p = .076$, $\eta^2 = .174$, for this interaction. Furthermore, the critical block effect approached significance, $F(1, 17) = 3.999$, $p = .062$, $\eta^2 = .19$. However, instead of an increase, error rates decreased from 4.74% in Block 10 to 3.81% in Block 11. All other interactions with the block factor were far from being significant (all *F*'s < 1).

As in Experiment 1, we calculated mean RTs and error rates in Block 11 separately for trials in which the mappings of card backs and target locations/identities corresponded (''old'') or did not correspond (''new'') to the mappings experienced in the 10 previous blocks. The ANOVA on the mean RTs with repeated measures on mapping (old vs. new) and imperative feature and response prediction as between-subject factors revealed no significant effects at all (all *p*'s > .13). The critical effect of mapping was far from being significant, $F(1, 17) < 1$, $\eta^2 = .004$. In the corresponding ANOVA over the error rates response prediction was the only factor that approached significance, $F(1, 17) = 3.680$, $p = .072$, $\eta^2 = .178$. When responses were predicted, the error rate amounted to 2.31% and increased to 5.09% when responses were not predicted. The critical mapping effect was again far from being significant, $F(1, 17) < 1$, $\eta^2 < .001$, as were all interactions with mapping (all *F*'s < 1).

Discussion

Experiment 2 replicated the basic results of Experiment 1. First, the portion of participants who became aware of the covariation was again larger when the responses were predicted as compared to the pure s–s covariations. The corresponding difference of respectively 7 versus 4 of 16 participants did not reach significance, however, $\chi^2(1) = 1.21$, $p > .1$. Second, when the covariations remained undetected, there was little evidence that covariations had much impact on performance. Although the predictive stimuli on the card backs were now the capital letters A and B, the data revealed no reliable indication of implicit learning. Thus, the suspicion can be ruled out that in Experiment 1 implicit learning was not found because of the predictive information being too vague. Few stimuli are more distinctive than letters. If they nevertheless do not start to prime the feature or the response they covary with, the failure is certainly not due to the predictive information being too vague or difficult to distinguish. Other reasons have to be considered.

In accordance with recent evidence for the impact attention has on implicit learning (cf. Jiménez, 2003a, 2003b), we suspect that Experiments 1 and 2 failed to show implicit covariation learning because participants did not attend to the predictive symbols on the card backs. In fact, all ''unaware'' participants consistently declared that they had noticed that there were different card backs but that they had not attended to them. Experiments 3 and 4 were designed to examine whether implicit covariation learning does indeed depend on the amount of attention the predictive informations attracts.

EXPERIMENT 3

The suspicion that attention might influence implicit learning emerged early in implicit learning research. Nissen and Bullemer (1987) argued in their seminal work on implicit sequence learning that attention plays an important role. Showing that implicit learning of a repeating sequence of stimuli disappeared when participants' attention was distracted by requiring them to count inserted tones, the authors concluded that ''subjects could learn the sequence without being aware of it, but not without attending to the task itself'' (p. 29; cf. Cohen et al., 1990; Frensch, Buchner, & Lin, 1994; Stadler, 1995). More recent studies showed that in particular attending to the predictive information is important.

In a study by Jiménez and Méndez (1999) participants responded to the locations of different shapes. In addition to a probabilistic sequence of locations/responses, the shape of the current stimulus predicted the location of the next stimulus (and the response) with a probability of .80. This predictive relationship improved performance when participants were to keep count of the number of trials in which either one of two target shapes occurred, that is when participants were to attend to the shapes. If, however, counting was not required, the covariation between shapes and locations was not learned. The authors concluded ''that paying attention to a predictive dimension is necessary for this dimension to enter as a predictor in a sequential relationship'' (p. 246).

Jiang and Chun (2001) extended the findings to visual search tasks. Participants searched either for green or red targets among distractors that were green as well as red. Furthermore, participants were instructed to attend to only the target colour, a procedure known to improve search performance (e.g., Treisman & Sato, 1990; Wolfe, Cave, & Franzel, 1989). When configurations of the distractors in the attended colour were consistently paired with target locations, search was improved significantly. In contrast, the same covariation between configurations of the distractors in the nonattended colour and target locations had no effect on search performance. The finding confirms that the predictive stimuli, in this case the configuration of distractors, have to be attended to in order to enter implicit learning.

In the present experiments, participants might have ignored the predictive card backs not only because the fish/palms or A's/B's were task-irrelevant, but also because they were placed on spatially separated distractor objects. There was no reason to attend to the cards with backs up, as all the information needed for correct responding was exclusively provided by the upturned cards. According to this speculation, predictive task-irrelevant information might be more likely to be used if it refers to features of the imperative target objects, instead of referring to features of spatially separated and irrelevant objects (e.g., Mulligan, 2002; Musen et al., 1999).

Experiment 3 was conducted in order to explore this consideration: Under otherwise identical conditions, two predictors of the respective response were compared. Both predictors were task irrelevant but centrally presented and clearly visible features of the display. One of the predictors was a distinct feature of the target objects that were to be attended to for correct responding. The other predictor was a distinct feature of an incidental but centrally presented object that needed not be attended to in order to accomplish the task. Thus, Experiment 3 aimed to vary the amount of attention the predictor attracts and explores the impact of this variation on implicit learning.

Method

Task and stimuli. In each trial, two decks with either fish or palms on the backs were presented in the upper left corner of a 15-inch VGA monitor. After a short delay, three cards of either of the two decks were distributed, horizontally aligned side by side in the centre of the screen, covering an area of 95 mm by 36 mm. Each individual card was 36 mm in height and 26 mm in width. Then, the two outer cards were flipped, whereas the back of the middle card remained visible (cf. Figure 5). The two upturned cards always differed in their values and participants were asked to look for the card with the higher (or lower) value and

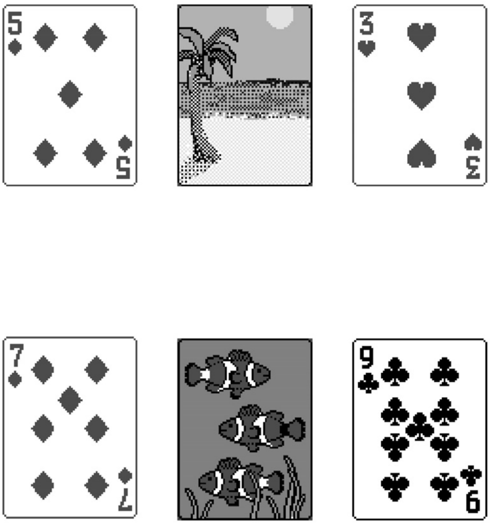

Figure 5. Illustration of the displays used in Experiments 3–6. Participants were requested to respond to the location of the card with either the higher or lower value.

to press the ‘‘left’’ cursor key to a ‘‘left’’ target and the ‘‘right’’ cursor key to a ‘‘right’’ target.

Design. The experiment was run in five blocks of 96 trials each. Only pairs of cards with the values 3–5, 4–6, 5–7, 6–8, and 7–9 were used, presented equally often in the given and in the reverse order. Pairs with suits of equal colour (black or red) contained cards from clubs–spades, spades–clubs, hearts–diamonds, and diamonds–hearts. Pairs with suits of unequal colours (one black, the other red) contained cards from hearts–spades, clubs–hearts, spades–diamonds, and diamonds–clubs. Each of the suit combinations was presented equally often. Half of the cards had fish and the other half had palms on their backs.

The required response was predicted with a probability of about 80%. The main variation concerned the predictor. For half of the participants, the symbol on card backs (fish or palms, group ‘‘back’’) was the predictor, whereas for the other half of the participants the equality of the colours of card suits (equal or unequal) predicted the response (group ‘‘colour’’). Thus, the predictive information was in one case an irrelevant feature of the middle card and in the other case an irrelevant feature of the two target cards.

In each block, there were 80 of the 96 pairs that complied with the respective predictive relation and 16 pairs that violated it. For example, in group ‘‘colour’’ there were 40 pairs with suits of equal colour (10 of each possible suit combination) that required a left response and 40 pairs with suits of unequal colours (10 of each possible suit combination) that required a right response (or vice versa). Additionally, there were eight pairs with suits of equal colour (two of each possible suit combination) that required a right response and eight pairs with suits of unequal colours (two of each possible suit combination) that required a left response (or vice versa). Whether responses were assigned to the location of the card with either the higher or the lower value and the mappings of the responses to the predictors (fish/palms or equal/unequal colours) were balanced between participants.

Procedure. The instruction explicitly stated that there were two different decks of cards with either fish or palms on the backs and that from any of the two decks three cards would be selected. Apart from that, flipping of the two outer cards and the respective assignment of the responses to the location of the card with either the higher or the lower value were explained, and participants were asked to respond as quickly and as accurately as possible. The index fingers of both hands rested on the response keys. Each trial started with the presentation of the two decks of cards. After 100 ms the three cards were ‘‘dealt’’ and after another delay of 1000 ms the two outer cards were flipped. The two upturned cards as well as the card back of the middle card remained visible on the screen until response onset. The latency between flipping of the cards and the key press was measured as RT in milliseconds. A short noise indicated response errors. The next trial started 1000 ms after the response. At the end of each block, participants were informed about the mean RT and error rate of the last block and they were asked to improve their performance until the last block.

At the end of the experiment, awareness of the covariation was explored through a standardised interview. First, participants were asked whether they had used any strategy in order to respond fast. Second, they were asked whether they had noticed anything special. Finally, they were told that the trials either with fish or palms on the card backs or with suits of equal or unequal colours were different and they were asked to state what this difference might have been. As we used probabilistic covariations, participants might choose not to report low confidence but consciously retrievable knowledge because of a high report criterion (Shanks & Johnstone, 1999). Therefore, we did not require that participants clearly stated the existence of a covariation in order to classify her or him as being aware of it. Rather, it sufficed that a participant remarked, for example, that s/he believed that with palms a right response was usually required, or that two red cards usually cooccurred with a left response, etc. Only if there was no such hint at the covariation having been noticed, the respective participant was considered as being unaware of the covariation. The total time to complete the experiment was approximately 35 minutes.

Participants. Forty students of the University of Würzburg took part in the experiment. The mean age was 22.55 years (*SD* = 3.40). There were 24 female and 16 male participants. Twenty participants each were randomly assigned to groups ‘‘back’’ and ‘‘colour’’.

Results

Exploratory analyses

According to the postexperimental interview, a majority of 32 participants were classified as being unaware of the predictive relationships. In group ‘‘back’’ seven participants became aware of the covariation. In group ‘‘colour’’ there was only one participant who apparently detected the covariation.

RT and accuracy data

RTs from error trials were discarded from the analysis (4.0% and 2.0%, in groups ‘‘back’’ and ‘‘colour’’ respectively; there were less than 0.1% outliers with RTs longer than 3000 ms). For each participant and block, the means of the remaining RTs and the error rates were calculated separately for the 80 predicted and for the 16 unpredicted responses in each block. Figure 6 presents the mean RTs plotted over blocks, separately for ‘‘aware’’ and ‘‘unaware’’ participants in groups ‘‘back’’ and ‘‘colour’’.

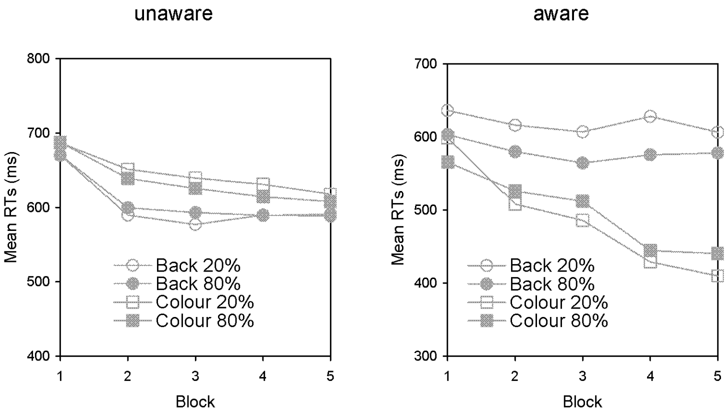

Figure 6. Mean RTs of ''aware'' and ''unaware'' participants in Experiment 3 for probable (80%) and improbable responses (20%) depending on the predictor (back of the middle card vs. colour of the two other cards).

Aware participants. The seven ''aware'' participants who detected the covariation between fish/palms and left/right responses (group ''back'') showed a substantial covariation effect: Predicted responses were faster (580 ms vs. 619 ms) and less error prone (3.0% vs. 10.0%) than unpredicted responses. The impact of the covariation on RTs, $F(1,6) = 22.105$, $p = .003$ as well as on error rates, $F(1,6) = 6.009$, $p = .05$, was significant. Figure 6 also presents the data of one participant who detected the covariation between equally/unequally coloured suits and left/right responses. We present the data of this participant for the sake of completeness only and refrain from any further interpretation.

Unaware participants. In order to explore whether there were different implicit effects subject to the predictor, the mean RTs and error rates of the ''unaware'' participants were subjected to an ANOVA with block (1–5) and prediction (predicted vs. unpredicted responses) as repeated measures and predictor (back vs. colour) as between-subject factor.

The ANOVA on the RTs revealed a significant main effect of block, $F(4,120) = 25.387$, $p < .001$, $\eta^2 = .458$. RTs decreased from 679 ms in Block 1 to 601 ms in Block 5. Furthermore, there was a significant interaction between prediction and predictor, $F(1,30) = 6.740$, $p = .014$, $\eta^2 = .183$. When colours were the predictor, predicted responses were faster than nonpredicted responses (635 ms vs. 645 ms). On the contrary, when card backs were the predictor, predicted responses were somewhat slower than unpredicted responses (609 ms vs. 603 ms). No other effect reached significance (all p's > .22). Separate ANOVAs for each predictor with block (1–5) and prediction (predicted vs. unpredicted responses) as repeated measures revealed a significant effect of prediction for the predictor ‘‘colour’’ but not for the predictor ‘‘back’’, $F_{\text{colour}}(1, 18) = 6.152$, $p = .023$, $\eta^2 = .255$; $F_{\text{back}}(1, 12) = 1.755$, $p = .210$, $\eta^2 = .128$.

The corresponding ANOVA on the error rates indicated the predictor as the only significant factor, $F(1, 30) = 4.197$, $p = .049$, $\eta^2 = .123$. The error rates for colours and card backs as predictors were 2.38% and 3.92%, respectively. The critical interaction between prediction and predictor failed to reach significance, $F(1, 30) = 2.786$, $p = .105$, $\eta^2 = .085$. The numerical data, however, corresponded to the interaction found with RTs: When colours were the predictor, error rates were reduced for predicted as compared to nonpredicted responses (1.86% vs. 2.90%). On the contrary, when card backs were the predictor, error rates were marginally increased for predicted as compared to nonpredicted responses (4.00% vs. 3.85%). All other effects failed to reach significance (all p’s > .19). Separate ANOVAs yielded a significant effect of prediction for the predictor ‘‘colour’’ but not for the predictor ‘‘back’’, $F_{\text{colour}}(1, 18) = 6.595$, $p = .019$, $\eta^2 = .268$; $F_{\text{back}}(1, 12) < 1$, $\eta^2 = .005$.

Discussion

Experiment 3 explored implicit learning of a probabilistic s–r covariation with a variation of the predictive stimulus. In one case the predictor was a feature of the targets that were to be attended to for correct responding. In the other case, the predictor was a feature of another object that was not to be attended to but was presented in between the two targets. Although both predictors consisted of clearly visible and distinct features of the display, implicit learning of the respective s–r covariation was only indicated if the predictive information was a feature of the target stimuli to which attention had to be directed. In contrast, if the required response was predicted by a distinct feature of an incidental object that participants did not need to attend to, no implicit but only explicit covariation learning was found. Thus, the data are consistent with the notion that a predictive stimulus needs to be attended to in order to enter implicit covariation learning. However, the conclusion needs further validation for at least two reasons.

First, the two predictors did not only differ with respect to the amount of attention they presumably attract but also with respect to the temporal relation between their onset and the onset of the targets. Whereas the presentation of the card backs preceded the onset of the targets, the colour predictor appeared with the targets because it was a feature of them. The observed differences in implicit learning might be due to this difference in temporal contiguity rather than to the extent to which attention is paid to the predictors. Experiment 4 will address this issue by presenting also the predictive card backs together with the targets.

Second, the conclusion that the failure to find implicit learning of the covariation between card backs and responses is due to a lack of attention remains speculation as long as there is no direct manipulation of the amount of attention the symbols on card backs attract. Accordingly, in Experiment 5 participants' attention was directed to the symbols on card backs by occasionally asking them to report the symbol on the card they just saw. We expected that implicit learning of the card back–response covariation can be obtained with this manipulation.

Besides the issue why the card back–response covariation is not implicitly learned, the found implicit learning of the colour–response covariation deserves discussion too. For an appropriate evaluation of this result it is to be noted that ''equal colours'' and ''unequal colours'' are categories that were each instantiated by four different suit combinations. That is, the predictor did not vary between two unique stimuli like between fish and palms but rather between eight different suit combinations. Participants were in no way forced to encode the combinations in accordance with the predictive categories. In contrast, participants were merely asked to look for the card with the higher (or lower) value, with no reason at all to encode, for example, a pair of hearts and diamonds as belonging to the same category as a pair of clubs and spades (equal colours). In other words, participants most likely did not experience a covariation between a binary predictive feature (equal vs. unequal colours) and a binary response but merely frequent coactivations of certain colour combinations with certain responses. Thus, for example, in each block, the left response was initiated 20 times after two red cards were checked and 20 times after two black cards were checked. These frequent coactivations seem to suffice to facilitate the activation of a left response if two red or two black cards are encoded concurrently. Experiment 6 further explores whether frequent coactivations of certain features and certain responses suffice in order to afford implicit learning.

EXPERIMENTS 4 AND 5

As in Experiment 3, there were three cards on the screen with the two outer cards upturned and the back of the middle card facing up. Participants were requested to respond (left or right) to the location of the card with the higher (or lower) value. The symbol on the back of the central card (fish or palms) predicted the currently required response with a probability of about .80. However, whereas in Experiment 3 the three cards were presented with their backs facing up before the two targets were turned over, now the upturned targets and the card back in between appeared together at the same point in time. Thus, in contrast to Experiment 3, the predictive card backs and the targets had a common onset in Experiment 4. In addition to the simultaneous presentation of predictor and targets, in Experiment 5 participants were occasionally asked to report the symbol on the back of the central card they had just seen. Accordingly, the back of the central card became a relevant stimulus for accomplishing this secondary task and should therefore attract attention in about the same way as the targets do in order to accomplish the primary task.

Method

Task and apparatus. The same task and apparatus were used as in Experiment 3.

Design and procedure. The same design and procedure were used as in Experiment 3, with the following exceptions: First, Experiments 4 and 5 explored implicit learning of a covariation between card backs and responses only. Second, in each trial, the three cards were presented with the two outer cards upturned from the outset. Third, in Experiment 5, participants were prompted to indicate the back of the middle card in 10 randomly selected trials in each block. In a corresponding trial, after the response a window appeared on the screen prompting participants to press the ‘‘f’’ key if there were fish, and the ‘‘p’’ key if there were palms on the back of the preceding middle card. The response was recorded and accuracy was fed back. Then the window disappeared and the block was continued with the presentation of the next three cards.

Participants. Twenty students of the University of Würzburg took part in Experiments 4 and 5, respectively. In Experiment 4 there were 16 female and 4 male participants. The mean age was 21.75 years (*SD* = 3.32). In Experiment 5 there were also 16 female and 4 male participants. The mean age was 21.55 years (*SD* = 3.80).

Results

Exploratory analyses

According to the postexperimental interview, a majority of 31 participants were classified as being unaware of the predictive relationship. In Experiment 4 only two participants became aware of the covariation. In Experiment 5, seven participants apparently detected the probabilistic covariation between the card backs they occasionally had to report and the required responses.

RT and accuracy data

RTs from error trials were discarded from the analysis (3.6% and 3.4%, in Experiments 4 and 5, respectively; there were less than 0.1% outliers with RTs longer than 3000 ms). For each participant and block, the mean of the remaining RTs and the error rates were calculated separately for the 80 predicted and for the 16 unpredicted responses in each block. Figure 7 presents the mean RTs

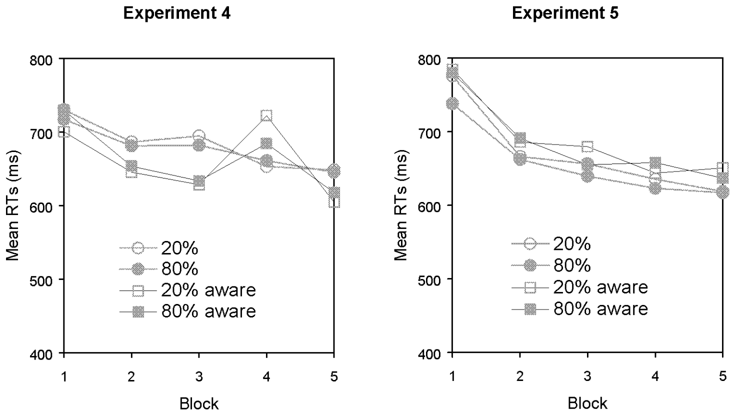

Figure 7. Mean RTs of ''aware'' and ''unaware'' participants in Experiments 4 and 5 for probable (80%) and improbable responses (20%). Responses were predicted by the back of the middle card.

plotted over blocks, for ''aware'' and ''unaware'' participants, separately for Experiments 4 and 5.

Aware participants. In Experiment 4 only two participants were classified as being aware, too few for statistical analyses and a reasonable discussion. Nevertheless, Figure 7 presents their data for the sake of completeness. In contrast to Experiment 3, the seven ''aware'' participants in Experiment 5 showed no covariation effect (cf. Figure 7): Predicted responses were only marginally faster (684 ms vs. 689 ms) and only marginally less error prone (3.4% vs. 3.9%) than unpredicted responses. However, both effects failed to reach significance, $F_{\mathrm{RT}}(1, 6) = 1.245$, $p = .307$, $\eta^2 = .172$; $F_{\mathrm{error}}(1, 6) < 1$, $\eta^2 = .038$.

Unaware participants. In order to explore whether the changes in comparison to Experiment 3, i.e., temporal contiguity (Experiment 4) and the additional manipulation of attention (Experiment 5), would result into implicit learning, the mean RTs and error rates of the ''unaware'' participants were subjected to separated ANOVAs with repeated measures on block (1–5) and prediction (predicted vs. unpredicted responses), and experiment (3 vs. 4 and 3 vs. 5) as the between-subject factor.

In comparing Experiment 4 with Experiment 3, the ANOVA over the RTs revealed a significant main effect of block, $F(4, 116) = 28.418$, $p < .001$, $\eta^2 = .495$. RTs decreased from 697 ms in Block 1 to 618 ms in Block 5. There was also a significant Block × Experiment interaction, $F(4, 116) = 3.300$, $p = .013$, $\eta^2 = .102$, which was mainly due to a steeper decrease of RTs from Block 1 to Block 2 in Experiment 3 (from 670 ms to 595 ms) than in Experiment 4 (from

724 ms to 684 ms). There was no main effect of prediction, $F(1, 29) < 1$: Whereas in Experiment 3 predicted responses were somewhat slower than unpredicted responses (609 ms vs. 603 ms) it was the reverse in Experiment 4 (677 ms vs. 683 ms). However, this critical interaction between prediction and experiment failed to reach significance, $F(1, 29) = 3.471$, $p = .073$, $\eta^2 = .107$, as also did the effect of prediction in a separate ANOVA over the data of Experiment 4 only, $F(1, 17) = 1.812$, $p = .196$, $\eta^2 = .096$. Finally, participants in Experiment 4 responded somewhat slower than participants in Experiment 3 (680 ms vs. 606 ms), $F(1, 29) = 4.855$, $p = .036$, $\eta^2 = .143$. All other effects were not significant (all p's > .25). In the corresponding ANOVA on the error rates, no effect reached significance (all p's > .26).

In comparing Experiment 5 with Experiment 3, the ANOVA on the RTs revealed a significant main effect of block, $F(4, 96) = 34.668$, $p < .001$, $\eta^2 = .591$. RTs decreased from 714 ms in Block 1 to 604 ms in Block 5. The interaction between block and experiment failed to reach significance, $F(4, 96) = 2.346$, $p = .060$, $\eta^2 = .089$. There was no main effect of prediction, $F(1, 24) = 1.867$, $p = .184$, $\eta^2 = .072$, but a significant interaction between prediction and experiment, $F(1, 24) = 9.547$, $p = .005$, $\eta^2 = .285$: Whereas in Experiment 3 predicted responses were somewhat slower than unpredicted responses (609 ms vs. 603 ms) they clearly were faster in Experiment 5 (656 ms vs. 671 ms). An ANOVA on the data of Experiment 5 only revealed this difference as being significant, $F(1, 12) = 8.605$, $p = .013$, $\eta^2 = .418$. No other effect reached significance (all p's > .13). The corresponding ANOVA on the error rates yielded no significant effects (all p's > .36).

Discussion

Experiment 4 explored whether the failure to find implicit learning of the card back–response covariation in Experiment 3 might have been due to the delay of 1000 ms between the onset of the predictive card backs and the onset of the targets. Accordingly, the predictive card backs and the targets were presented simultaneously. As a result, predicted responses were now slightly faster than unpredicted responses. However, this 6 ms effect was too small to reach significance. Thus, we can not exclude that the temporal contiguity of the predictive information and the predicted response might have an influence on implicit learning but we conclude that it is not a crucial factor in the range which has been explored in the present experiments, i.e., up to 1 s (cf. Elsner & Hommel, 2004). Accordingly, the failure to find implicit learning of the card back–response covariation in Experiment 3 was probably not due to insufficient temporal contiguity.

Experiment 5 was designed in order to verify the assumption that Experiment 3 failed to find implicit learning of the card back–response covariation because the card backs were not sufficiently attended to. Accordingly, participants' attention was directed to the card backs by occasionally prompting them to report the back of the previously presented cards. As a result, implicit learning was now reliably indicated. The finding confirms the general claim that attention to the predictive information is important for implicit covariation learning to occur.

It has to be noted that in contrast to Experiment 3 the ''aware'' participants in Experiment 5 apparently made no use of the detected covariation as predicted responses were not superior to unpredicted responses. We see two likely accounts for this finding: First, as the predictor was presented together with the targets, an intentional prediction of the required response would most likely interfere with the search for the target so that participants would not benefit from predictions. Second, the fact that the symbols on the card backs were to be memorised for a possible prompt might also have prevented a simultaneous voluntary prediction of the required response.

EXPERIMENT 6

In Experiment 3 we found implicit learning of a colour–response covariation. The colour variable referred to eight suit combinations (four each for suits with equal and unequal colours) and the response variable consisted of only two responses (left and right). As it appears unlikely that participants spontaneously categorise the eight suit combinations according to the predictive equality of colours (equal vs. unequal), we assumed that the observed advantage for predicted responses results from repeated coactivations of certain suit codes and certain response codes. In other words, we assume that for implicit covariation learning to occur it does not need true covariations between two variables but merely coactivations of distinct codes. Accordingly, *partial* covariations should suffice to induce covariation learning. For example, imagine left and right responses triggered by a stimulus display showing either red or green dots among others. If the left response is frequently initiated in the presence of red dots, activating the feature ''red'' should selectively prime a left response, irrespective of how often the right response went along with red or green dots (cf. Hommel, 1998). Experiment 6 examines the behavioural effects of such a partial s–r covariation.

As in Experiment 3, participants were to respond (left or right) to the location of the card with the higher (or lower) value, and the equality or inequality of the colours of card suits (equal or unequal) predicted the current response. However, in contrast to Experiment 3, the predictive relationship existed only for one of the two responses. For example, the left-hand response was triggered by a pair of cards with suits of equal colour in about 80% and by a pair of cards with suits of unequal colours in about 20% of all cases. The right-hand response, however, was equally frequently required by pairs of cards with either suit of equal or unequal colours. If, as we assume, implicit covariation learning merely is based on the coactivation of distinct representations, responses of the ‘‘indicative’’ left hand should be selectively accelerated by equally coloured suits, whereas responses of the ‘‘neutral’’ right hand should remain uninfluenced by suit colours.

Method

Task and apparatus. The same task and apparatus was used as in Experiment 3.

Design. The experiment used the same design and stimulus material as Experiment 3, except that there was only a partial covariation between the predictive colour equality of suits and one of the two responses. Accordingly, in each of the five blocks there were 40 pairs that fulfilled the respective predictive relation and 8 pairs that violated it. For example, if colour equality predicted the left response, there were 40 pairs with suits of equal colour (10 of each possible suit combination) and 8 pairs with suits of unequal colour (2 of each possible suit combination) that required a left response. Additionally, there were 24 pairs with suits of equal colour and 24 pairs with suits of unequal colour (6 of each of the possible suit combinations respectively) that required a right response. Whether participants had to respond to the location of the card with the higher or the lower value as well as whether equal or unequal colours predicted the response of the left or the right indicative hand were balanced between participants.

Procedure. The same procedure was used as in Experiment 3.

Participants. Sixteen students of the University of Würzburg took part in the experiment. There were 10 female and 6 male participants. The mean age was 22.5 years (*SD* = 3.65).

Results

Exploratory analyses

Fourteen participants were classified as being unaware of the predictive relationship. Only two participants supposed that there might have been a relation between the equality of the colours of the two suits and the response side, however, without mentioning that the relation was restricted to one hand.

RTs and accuracy data

RTs from error trials were discarded from the analysis (3.5%; there were less than 0.1% outliers with RTs longer than 3000 ms). For each participant and block, mean RTs and error rates were calculated, first for the 40 trials in which

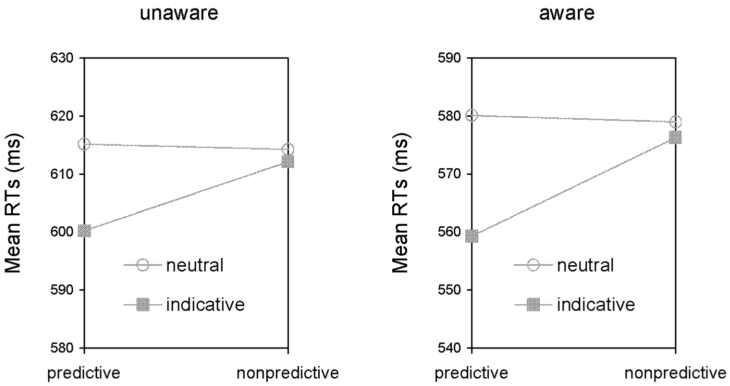

Figure 8. Mean RTs of ''aware'' and ''unaware'' participants in Experiment 6 for the indicative and the neutral response to targets with predictive and nonpredictive features. As the block factor did not interact with any of the other variables, the data were collapsed over blocks.

the predictive relation between colour equality and the response of the indicative hand was fulfilled, second for the 8 trials in which this predictive relation was violated, third for the 24 trials in which the response of the neutral hand was triggered by a pair of suits that were predictive for the indicative hand, and fourth for the 24 trials in which the response of the neutral hand was triggered by pairs of suits that were nonpredictive for the indicative hand. Figure 8 presents the mean RTs for the indicative and the neutral hand plotted against predictive and nonpredictive card pairs, separately for the 14 ''unaware'' and the 2 ''aware'' participants.

Aware participants. The data of the two aware participants are presented for the sake of completeness. Responses of the indicative hand were faster to predictive than to nonpredictive suit pairs (559 ms vs. 576 ms), whereas responses of the neutral hand were not affected by the colours of the suits (580 ms vs. 579 ms). Although these participants did not report to have noticed the partial character of the covariation, their hands apparently adapted to it.

Unaware participants. In order to explore implicit effects of the partial covariation, the mean RT and error data of the ''unaware'' participants were subjected to an ANOVA with repeated measures on block (1–5), hand (indicative vs. neutral), and prediction (predictive vs. nonpredictive suit combinations).

The ANOVA on the RTs indicated a main effect of block, $F(4, 52) = 12.350$, $p < .001$, $\eta^2 = .467$, a marginally significant effect of hand, $F(1, 13) = 4.563$, $p = .052$, $\eta^2 = .260$, and a significant interaction between hand and prediction, $F(1, 13) = 5.321$, $p = .038$, $\eta^2 = .290$. RTs decreased with practice (from 654 ms in Block 1 to 577 ms in Block 5), responses with the indicative hand were slightly faster than responses with the neutral hand (606 ms vs. 615 ms), and the predictive information only affected RTs of the indicative hand (600 ms vs. 612 ms) but not RTs of the neutral hand (615 ms vs. 614 ms). All other effects failed to reach significance (all *p*'s > .08). A one-tailed *t*-test revealed the acceleration of responses of the indicative hand to predictive as compared to nonpredictive suit combinations as being significant, $t(13) = 2.126$, $p = .0265$.

The corresponding ANOVA on the error rates yielded neither significant main effects nor significant interactions (all *p*'s > .2). However, the error data numerically showed the same trends as the RT data: Error rates slightly decreased with practice (from 4.0% in Block 1 to 3.2% in Block 5), responses of the indicative hand were less error prone than those of the neutral hand (3.3% vs. 4.1%), and the predictive information affected the error rates of the indicative hand (2.7% vs. 3.9%) more than the error rates of the neutral hand (4.0% vs. 4.1%).

Discussion

Experiment 6 was conducted in order to explore whether a partial probabilistic covariation, in which certain stimuli were frequently coactivated with an ''indicative'' response but were uncorrelated with another ''neutral'' response, would selectively affect the two responses. The data confirmed this: Although the majority of participants did not notice the partial covariation, the latencies of the indicative response were significantly reduced when required by frequently coactivated stimuli. In contrast, the latencies of the neutral response were not affected by the corresponding stimuli. The finding is consistent with the general notion that coactivations of certain stimulus codes and certain response codes suffice in order to form relations between the evoked representations, so that the initiation of a certain response is facilitated if required by stimulus codes which has been associated to it.[2]

GENERAL DISCUSSION

Implicit learning of covariations between predictive stimuli and targets or responses has attracted considerable interest. In order to ensure that participants remain unaware of the covariations, the predictive stimuli have often been presented hidden or subliminally. The results of these studies are inconsistent.

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[2] If RTs would be solely determined by the contiguity of stimulus and response codes, the latencies of the indicative response to the seldom stimulus should have been delayed in comparison to the latencies of the neutral response (8 vs. 24 coactivations per block). This was not the case (612 ms vs. 614/615 ms), which suggests that responses are not purely stimulus driven but are also driven by the readiness to perform them. In the present case both responses were equally often required so that participants were presumably equally ready to perform each of them.

Several studies reported evidence for implicit covariation learning (e.g., Chun & Jiang, 1998, 1999, 2003; Flowers & Smith, 1998; Lambert et al., 1999; Lewicki, 1986a, 1986b; Lewicki, Hill, & Czyzewska, 1992), whereas other studies failed to demonstrate implicit covariation learning (e.g., Hendrickx et al., 1997a; Hoffmann et al., 2003; Jiang & Chun, 2001; Wolff & Rübeling, 1994). Besides the extensive discussion whether appropriate methods were used for assessing awareness (Holender, 1986; Lovibond & Shanks, 2002; Shanks & St. John, 1994), the contradictory results provoke the question of which conditions might be critical for implicit covariation learning to occur (cf. Hendrickx et al., 1997b; Lewicki et al., 1997). The present experiments were designed in order to contribute to an elucidation of such conditions.

Experiments 1 and 2 compared implicit learning of stimulus–stimulus (s–s) and stimulus–response (s–r) covariations. Participants performed a visual search task. A distinct feature of the search display reliably predicted either the location or the identity of the target one of which participants were to respond to. Accordingly, participants experienced either a deterministic s–s covariation or a deterministic s–r covariation. Although the predictive feature always was a central aspect of the search display, most participants reported that they had neither attended to it nor detected the predictive relationships. Moreover, performance of these ‘‘unaware’’ participants remained uninfluenced by the respective predictive relation—even if the predictive features were as intrusive as the centrally presented letters A and B. Thus, neither s–s nor s–r covariations seem to address implicit learning mechanisms automatically. The failure to find implicit covariation learning, despite the presented covariations being obvious and in no way hidden, suggests that even clearly visible and distinct predictors need to be attended to in order to enter implicit learning mechanisms, irrespective of whether an s–s or an s–r covariation is concerned.

Experiments 3–5 directly explored the impact of attention on implicit s–r learning. In Experiment 3, one of two distinct features of the current display predicted the required response with a certainty of about 80%. For one group of participants an irrelevant feature of the imperative targets predicted the response. For another group, the predictor was a feature of an incidental but central object. Although both predictors were comparably distinct, implicit covariation learning only occurred when a feature of the to-be-attended targets predicted the response. In contrast, when the predictive information referred to the irrelevant object, which was not to be attended to, no implicit learning was indicated. Experiment 4 additionally shows that the different efficiency of the two predictors is most likely not due to different time relations between the onset of the predictive and the onset of the imperative information. Moreover, Experiment 5 shows that the formerly inefficient predictor becomes efficient if it attracts attention in the context of a corresponding secondary task. The results are consistent with the general conclusion that predictors need to be attended to in order to enter implicit learning mechanisms, however obvious and distinct they may be.

Finally, in Experiment 6, participants experienced a *partial* covariation between irrelevant target features and two responses: Only the ‘‘indicative’’ response frequently went along with certain target features, whereas for the ‘‘neutral’’ response all target features were equally frequent. The results showed implicit effects of the partial s–r covariation only for the ‘‘indicative’’ response. The ‘‘neutral’’ response remained uninfluenced by any target features. Hence, both responses became independently associated with target features according to the frequencies with which the respective response and the respective feature were simultaneously activated.

Altogether, the data lead us to the conclusion that implicit covariation learning might be based on nothing else than the formation of associations between simultaneously activated distinct representations (see, for similar views, Frensch & Miner, 1994; Hommel, 1998; Jiménez, 2003b; Jiménez & Méndez, 1999; Logan & Etherton, 1994; Logan, Taylor, & Etherton, 1996). If two distinct representations are simultaneously active sufficiently frequently, they become associated with each other in the sense that the one tends to facilitate the activation of the other. Thus, if a response is frequently initiated in the presence of a certain stimulus, the response will be accelerated if it is required in the presence of this stimulus again. Naturally, all this occurs only if the respective items evoke distinct representations as otherwise individual associations can not be formed. And for this to happen, attention seems to be necessary. From this perspective, attention lays the foundations for covariation learning to take place: Without attention there are no distinct representations and without distinct representations there is no learning.[3]

The finding that even clearly visible and distinct predictors fail to become effective unless being attended to fits in with recent evidence showing that humans often remain ‘‘blind’’ for centrally presented but nonattended stimuli (Mack & Rock, 1998). Likewise, it has been suggested that ‘‘blindness’’ to changes in flickering pictures only occurs when participants do not attend to the changing stimuli (e.g., Hollingworth & Henderson, 2002; Hollingworth, Williams, & Henderson, 2001; Rensink, O’Regan, & Clark, 1997). Furthermore, Wolfe, Klempen, and Dahlen (2000) reported that repeatedly searching the same display for varying targets only marginally improves search efficiency. Obviously, sketchily scanning the distractors does not suffice to evoke retainable object codes that can be addressed if a former distractor becomes a target all this evidence points to the notion that an object or a stimulus has to be attended to in order to evoke a distinct representation of it; and evoking distinct representations

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[3] These considerations echo the established insight that even animals do not ‘‘willy-nilly’’ form associations between any two stimuli that happen to cooccur (Rescorla, 1988). There are several theories of animal learning that explicitly claim that a stimulus has to be attended to in order to enter an associative connection (e.g., Holyoak, Koh, & Nisbett, 1989; Mackintosh, 1975; Pearce & Hall, 1980; Wagner, 1981).

is an indispensable prerequisite for a stimulus to enter individual associative relations.

Whether the evolving associations themselves reach awareness is yet another question. The present results confirm the common assumption that a conscious detection of a covariation or ‘‘*contingency awareness*’’ (Lambert et al., 1999) is not necessary, neither for representations to become associated nor for the association to affect behaviour. Experiments 3, 5, and 6 showed significant behavioural effects of probabilistic covariations for participants who apparently were not aware of them. In general, we sympathise with views according to which the probability of entering ‘‘awareness’’ is considered as being dependent on the quality of the underlying representations, that is on their distinctiveness, relative strength, or stability (e.g., Cleeremans & Jiménez, 2002; Dienes & Berry, 1997; Dienes & Perner, 1999; Frensch, Haider, Rünger, Neugebauer, Voigt, & Werg, 2003; Kanwisher, 2001). Although these conceptions differ with respect to assumptions concerning when and how represented contents enter awareness, they agree in that associations might be formed that are strong enough to affect behaviour but are too weak to enter awareness. In any case, the present experiments show that even for such weak associations to be formed, the involved items have to be attended to.

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