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Mood Influences the Formation of Explicit Knowledge but not Learning of Implicit Regularities

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Abstract

The affect-as-information hypothesis states that negative mood results in a more analytic and positive mood in a more heuristic processing style. Evidence comes from a wide range of research areas, e.g., on memory or person perception. Studies on implicit learning, however, are scarce and evidence mixed. Therefore, the present study examined the influence of mood on implicit sequence learning and the formation of explicit knowledge. An incidental sequence learning task was used during which negative, neutral, and positive background pictures were used to induce mood states in three groups of participants. Consistent with the affect-as-information hypothesis, the results show that a less positive mood resulted in more explicit sequence knowledge. In contrast, positive mood did not enhance implicit learning. It is speculated that implicit regularity learning as an automatic by-product of task processing might be less susceptible to affective processing biases than other, more complex types of cognitive processing.
Key words: sexual assault, forensic interview, delayed reporting, FETI interview, consumer acceptability.

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Novelty and Significance

What is already known about the topic?

- Affective states can influence information processing.
- Positive affect is usually associated with a relational and holistic processing style, while negative affect leads to a more analytic processing style.
- Studies on affective influences on implicit learning are rare, and results are mixed.

What this paper adds?

- We address shortcomings in earlier research on mood influences on implicit learning.
- The results show that a more negative mood resulted in more explicit sequence knowledge probably via more analytical processing.
- In contrast to expectations, mood did not modulate implicit learning, which can be seen as automatic by-product of task processing and might thus be less susceptible to affective biases than other types of cognitive processing.

It is well established that affective states can influence how we process information. The affect-as-information hypothesis (Clore, Wyer, Dienes, Gasper, Gohm, & Isbell, 2001; Schwartz & Clore, 1983) explains this by stating that affective states, like moods or emotions, provide important information about the situation one experiences or persons or objects one is interacting with and create a readiness to react in a certain way. In the simplest case, positive mood or emotions indicate that the current environment is safe, pleasant, and beneficial for the individual. In contrast, negative emotions can signal unpleasant situations, harmful environments, or even imminent danger (cf. Frijda, 2016). Therefore, positive affect is usually associated with a relational and holistic processing style, while negative affect leads to a more analytic, perceptual, and detail-oriented processing style (e.g., Clore & Huntsinger, 2007; Storbeck & Clore, 2007).

In accordance with this idea, the influence of mood and emotions on cognition have been demonstrated in several domains (for a review, see Bless & Fiedler, 2006).

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For example, it has been shown that negative mood leads to better memory recall as opposed to positive mood (Forgas, Goldenberg, & Unkelbach, 2009). In contrast, positive mood increases false memories of words closely associated with the presented words (Storbeck & Clore, 2005). In the domain of semantic priming, Hanze and Hesse (1993) were able to demonstrate that participants in a positive as compared to a negative mood activated semantically related concepts more reliably. Beukeboom and Semin (2006) found that mood influences language use by showing that film-induced positive mood results in the use of more abstract linguistic expressions when participants were asked to describe autobiographical events or film scenes, while negative mood led to more concrete language. Moreover, it has been shown that people in a positive mood are more likely to use stereotypes when judging other persons (Bodenhausen, Kramer & Süsser, 1994; Isbel, 2004) and that primacy effects of first impressions were increased by positive mood and eliminated by negative mood (Forgas, 2011).

Although the reported studies comprise different cognitive domains including explicit as well as implicit processing, affective influences on implicit learning have been examined in only a handful of studies.

On a conceptual level, implicit learning can be defined as "a complex form of priming taking place in continuously learning neural systems" that "can be causally efficacious in the absence of awareness that this knowledge was acquired or that it is currently influencing processing" (Cleeremans, Destrebecqz, & Boyer, 1998, p. 406). A common working definition is that implicit learning has taken place when new information has been incidentally acquired and the resulting knowledge is hard to express verbally (Berry, 1994; Frensch, 1998; Reber, 1989; Seger, 1994; for a review, see Cleeremans *et alii*, 1998).

A frequently used paradigm to study implicit learning is the sequence learning task (SRT; Nissen & Bullemer, 1987). In the classical version of this task visual stimuli are presented in one of four possible locations on a computer screen. The participant's task is to press the response button that corresponds to the location of a stimulus as fast as possible after its presentation. Stimuli are presented in a repeating sequence, but participants are not informed about this fact. However, when after some training on the repeating sequence this sequence is exchanged with an untrained sequence, usually a marked increase in reaction times is obtained. This increase in reaction times also persists when participants that became aware of the repeating nature of the sequence during training are excluded from data analysis. Therefore, this reaction time difference is taken as an index for implicit learning, and it is assumed that sequence knowledge is acquired incidentally and without the assistance of conscious learning processes (Destrebecqz & Cleeremans, 2001; Eimer, Goschke, Schlaghecken, & Stürmer, 1996; Nissen & Bullemer, 1987; Rüsseler, Kuhlicke, & Münte, 2003; Rüsseler, Hennighausen, Münte, & Rösler 2003). However, although sequence learning does not require explicit learning, explicit processes such as the knowledge about hidden regularities can enhance sequence learning (e.g., Curran & Keele, 1993; Ferdinand & Kray, 2017; Ferdinand, Mecklinger, & Kray, 2008; Ferdinand, Rünger, Frensch, & Mecklinger, 2010).

In a study by Braverman (2005), the effect of a happy, sad, and neutral mood state induced via short video clips on the detection of covariation in photographs of different persons (nose width and verbal/ math ability) was examined. In addition to implicit learning of the covariations, the results demonstrated, that participants in a sad mood state explicitly noticed the covariation more often than did participants in the happy and neutral mood states as measured by a free recall. According to the mood-as information theory, this could be explained by the more analytic processing style of participants in a sad mood state. Pretz, Totz, and Kaufman (2010, 2014) investigated the influence of emotional pictures in two types of implicit learning, artificial grammar learning and sequence learning. Before the learning paradigms, participants viewed 50 pictures of positive (e.g., smiling faces, food, beautiful nature), negative (e.g., drug use, disease, war and death), or neutral (e.g., everyday objects, landscapes) photographs from the International Affective Picture Scale (IAPS, Lang *et alii*, 1997) that were controlled for valence and arousal. Afterwards, the Positive Affect Negative Affect Scale (PANAS, Watson, Clark, & Rellegen, 1988) was filled out to judge the emotional state of the participants before the two learning tasks were administered. They found that participants in a negative mood outscored those in a positive and a neutral mood in the artificial grammar learning task, but inconsistent with this result, this was not the case in the sequence learning task (Pretz *et alii*, 2010, 2014). Shang *et alii* (2013), analyzed sequence learning using a probabilistic sequence including a shape as well as a more-complex shape-color regularity. To induce positive, negative, and neutral mood states, classical music pieces were used. The mood induction took place before the learning task (in experiment 1) and was additionally repeated several times throughout the task (in experiment 2). They found that learning of the shape regularity was worse in the negative as compared to the positive or neutral mood group. Surprisingly, and in contrast to the affect as information theory which assumes a more analytic and hypothesis-driven processing style in negative mood states, hints of explicit knowledge were found in the positive mood group, only.

Taken together, there is only a handful of studies exploring the influence of mood on implicit learning. Moreover, the evidence from these studies is rather mixed, ranging from better implicit learning in negative than positive mood (Braverman, 2005), which is in accordance with the affect-as information hypothesis (Clore *et alii*, 2001, Schwartz & Close, 1983), to impaired implicit learning in negative mood (Shang *et alii*, 2013). Additionally, these earlier studies also have some limitations which could account for these mixed findings. First, the type and duration of the mood inductions used may have influenced the results. For example, Pretz *et alii* (2010, 2014) induced mood via IPAS pictures that were shown before the implicit learning paradigms were conducted. Similarly, Shang *et alii* (2013) showed videos before the start of the learning task. Although in their second experiment, they applied mood refreshers during the learning task, it is not clear how far into the learning task these induced mood states are in effect and actually influence implicit learning. Second, to test whether mood states were actually induced by the photographs, music, or video clips, rating scales (e.g., the PANAS) were used before the implicit learning task was conducted (e.g., Pretz *et alii*, 2010, 2014) or even several times throughout the experiment. Although the intent of this procedure, to check whether the mood induction actually influenced participants' mood states, is clear, it could have drawn participants' attention to their mood or even the fact that a mood induction had taken place and therefore influenced the results, e.g., by emotion regulation counteracting (negative) mood states. Third, the studies reported above did not apply tests of explicit knowledge after learning and thus did not exclude those participants with explicit knowledge. Because participants with explicit knowledge usually also have the largest learning effects, better performance, e.g., after negative mood induction (for instance in the artificial grammar learning task of the study by Pretz *et alii*, 2010, 2014), could in principle be linked to more explicit knowledge that was acquired in this condition.

The present study aimed at investigating the effect of mood states on implicit learning and the acquisition of explicit knowledge. To this end, an incidental sequence learning task was used. To achieve a long-lasting effect of mood, we used emotional (positive and negative) and neutral background pictures for mood induction that were presented throughout the task. After the task, participants completed a mood rating and explicit knowledge acquisition was tested by means of a semi-structured interview including a free recall of the sequence and a process dissociation procedure.

The affect-as-information hypothesis (Clore *et alii*, 2001; Schwartz & Clore, 1983) assumes that positive mood states indicate that the current environment is safe, pleasant, and beneficial for the individual, while, negative emotions signal unpleasant situations, harmful environments, or danger (cf. Frijda, 2016). Therefore, positive affect is usually associated with a relational and holistic processing style, while negative affect leads to a more analytic, perceptual, and detail-oriented processing style (e.g., Clore & Huntsinger, 2007; Storbeck & Clore, 2007). As implicit learning is usually described as effortless, associative, bottom-up, and heuristic process (Chaiken & Trope, 1999; Cleeremans et alii, 1998), in accordance with the affect-as-information hypothesis, we expected that positive mood would strengthen implicit learning. The formation of explicit knowledge during incidental learning, in contrast, is assumed to require an effortful, top-down, and analytic processing style (Rünger & Frensch, 2008) and should thus result in the emergence of more explicit knowledge. This second hypothesis can also be derived from the unexpected-event hypothesis (Frensch *et alii*, 2003; Haider & Frensch, 2005; Lustig, Esser, & Haider, 2021). It states that the accumulation of implicit sequence knowledge leads to more and more incidents in which participant observe unexpected behavior (i.e., responding correctly even before or very soon after the stimulus has been shown). These observations are supposed to trigger intentional search process (i.e., checking the material for how it is possible to react so quickly). Thus, negative mood might potentially make the triggering of such search processes more likely.

METHOD

Participants

An *a-priori* sample calculation showed that with a power of $1\text{-}\beta= 0.9$ and $\alpha= 0.05$, a sample of 99 participants has the sensitivity to detect a between-within interaction of a medium effect size of $f= 0.2$ in a 3×2 mixed factors ANOVA (Faul *et alii*, 2007). Because we expected drop-out due to explicit sequence knowledge, 150 participants (*M* age= 21.7 years, 118 female) were recruited for this study via the University of Wuppertal's digital study system (Sona Systems) or via flyers that were distributed at the university or in its vicinity. 142 of them were students at the University of Wuppertal and received course credit for their participation. Eight participants had received their high school diploma but were not studying at the time of their study participation and did not receive any study compensation. Participants were randomly assigned to the three groups with 50 participants, respectively, that received a different mood manipulation (for a description of the sample see Table 1). According to self-report, all participants were free of psychological and neurological illness and had normal or corrected to normal vision. The study was in accordance with relevant laws, institutional guidelines, and with the ethical guidelines of the Declaration of Helsinki and received approval by the Ethics Committee of the University of Wuppertal (SK/AE 240603). Privacy rights of human subjects have been observed. All participants signed informed consent before the study started and were informed about the goals of the study after study participation.

Table 1. Sample description.

	Groups		
	Negative Backgrounds	Neutral Backgrounds	Positive Backgrounds
Mean Age (years) (*SD*)	21.6 (2.9)	22.1 (3.5)	21.3 (3.9)
Sex (male/female)	12/38	10/40	10/40

Task and Stimuli

During the sequence learning experiment, we applied a modified version of a sequence learning task, (cf. Ferdinand *et alii*, 2010; Ferdinand & Kray, 2017; see Figure 1). In this task, a large colored rectangle is presented in the middle of the screen. Below this, six smaller colored target rectangles are placed. To each of these targets, a spatially compatible response key is assigned, i.e., the alignment of the six response keys corresponds to the alignment of the six target rectangles on the screen. The participants' task is to decide on each trial which target rectangle is assigned the same color as the larger rectangle in the middle of the screen and to respond by pressing the spatially corresponding key on a response keyboard as fast as possible. They responded to the target rectangles with the ring, middle, and index fingers of their left and right hand. The same six colors (green, red, yellow, gray, pink, and blue) were used in every trial, but each rectangle changed its color pseudo-randomly from one trial to the next.

On any given trial, the top rectangle and the six target rectangles were displayed simultaneously for 1500 ms, followed by a blank screen for 150 ms. Participants were

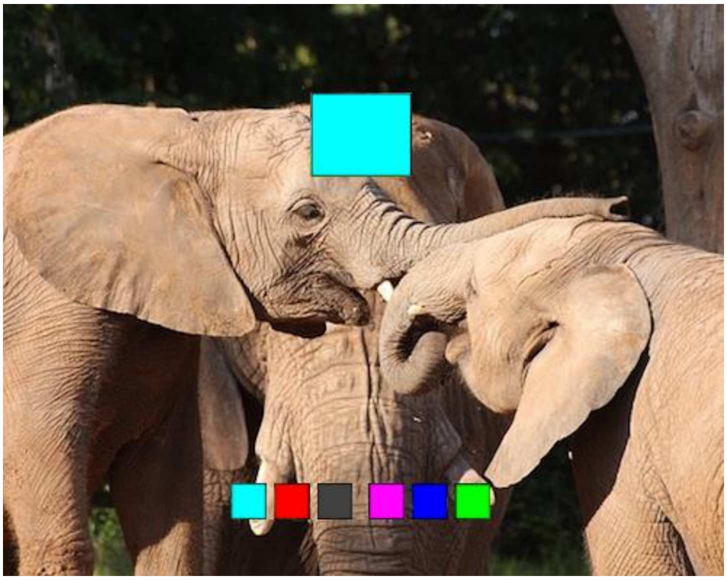

Figure 1. Example for an (emotionally positive) stimulus display in the serial reaction time task (SRTT). Pictures were taken from the OASIS database (Kurdi, Lozana, & Banaji, 2017).

required to respond within 1500 ms after stimulus onset. If no response or an erroneous response was given during that time, the visual feedback “zu langsam” (too slow) or “falsch” (wrong) was shown for 700 ms. Response locations during the sequence learning task followed one of two repeating 6-element first-order conditional sequences (cf. Reed & Johnson, 1994). These two sequences (1-5-2-6-4-3 and 1-3-6-2-5-4) were taken from Ferdinand & Kray (2017). One of these two sequences was used as the training sequence for a participant and the other was used as the untrained sequence. Which sequence served as training/ untrained sequence was counterbalanced over participants and. Importantly, the response location on any given trial was predictive of the response location on the next trial. The SRTT contained no further sequential regularities other than the repeating sequence of response locations (for more details on how these sequences were created, see Ferdinand *et alii*, 2010).

To induce mood, we used pictures from the OASIS database (Kurdi, Lozana, & Banaji, 2017) as background for the rectangles. Participants were divided in three groups of 50 individuals. One group received positively valenced background pictures that were displayed behind the colored rectangles, one group received negatively valenced pictures and one group saw emotionally neutral pictures as background pictures. Participants in each group saw 12 different background pictures, respectively. Pictures were chosen to have clearly different valence ratings (mean negative= 2.59, mean neutral= 4.29, mean positive= 5.75), but similar arousal ratings (mean negative= 4.18, mean neutral= 3.78, mean positive= 3.94).

Participants were told that they were taking part in an experiment designed to examine the ability to discriminate colors from different naturalistic backgrounds. They were not informed about the role of the emotional content of the background pictures nor about the fact that correct response locations during the training phase followed a repeating pattern. Thus, learning of the sequential regularity was incidental.

All three groups first practiced the SRTT (without background pictures) with 24 warm-up trials during which response locations were determined randomly. During the main experiment, each participant performed 16 experimental blocks including 60 trials (10 sequences) respectively. Blocks 1 to 7 and 9 to 15 were comprised of the repeating training sequence only. Block 8 and block 16 included a switch to the untrained sequence and were used to analyze learning effects (block 7 vs. 8 and block 15 vs. 16, respectively). Twelve different background pictures were used for each participant. Each of these pictures was presented eight times in random order and was visible in the background for 10 trials in a row, respectively. If error rate exceeded 15 % or timeouts exceeded 10 % per block, participants were prompted to make fewer mistakes or to respond faster.

After completion of the SRTT, participants were asked to rate their present mood on a continuous scale of zero to ten, with zero denoting a negative mood and ten denoting a positive mood. They also rated their present arousal on a scale of zero (low arousal) to ten (high arousal). Additionally, they were asked to judge in retrospect whether and to what extent the background pictures had elicited positive or negative feelings during the experiment again on a continuous scale of zero (strong negative feelings) to ten (strong positive feelings). Then, their reportable knowledge about the training sequence was assessed in a semi-structured interview. First, they were asked whether they (a) had noticed anything unusual during the experiment; and (b) had noticed a repeating pattern in the stimulus presentation. If they had not noticed a repeating pattern by themselves, the experimenter explained that responses in the training phase followed a regular pattern and asked the participant to verbally describe the serial order of response locations by referring to the letters on the keyboard on the respective response keys. In order to prevent any spontaneous typing activity, participants had to cross their arms in front of their upper body and hold a pencil in each hand while attempting to report the sequence.

After free recall of the sequence, participants conducted a sequence production task adapted from the process dissociation procedure (Jacoby, 1991, 1998), in order to identify explicitly learned sequence parts (cf. Ferdinand & Kray, 2017; Ferdinand et alii, 2010). Subjects were asked to produce three six-letter sequences using the same six response keys as during sequence learning under an inclusion and an exclusion condition, respectively. In the inclusion condition, they were to type the repeating regular sequence, whereas in the exclusion condition they were to avoid it. Simply pressing the response keys in their spatial (forward or backward) order was not allowed. The rationale behind this sequence production task is that participants without explicit knowledge of the repeating sequence should have trouble discriminating between these constraints, and therefore, would produce similar sequences in both conditions, whereas subjects with explicit sequence knowledge should have control over the sequences they produce and thus have no problem to follow the instructions (see also Destrebecq & Cleeremans, 2001; Ferdinand et alii, 2008; Schlaghecken, Stürmer, & Eimer, 2000).

Procedure

After signing informed consent, participants filled out a short demographic questionnaire before the main task of the experiment, the sequence learning task (SRTT), started. After completion of the SRTT, participants were asked to rate their present mood, arousal, and whether and to what extent the background pictures had elicited positive or negative feelings. Then, their reportable knowledge about the training sequence was assessed and the sequence production task was completed.

Data Analyses

To check whether the emotional background pictures actually induced mood states, we first analyzed participants' mood ratings, arousal ratings, and the responses to the question of whether and how much the background pictures induced positive or negative feelings during the experiment. For this purpose, planned contrasts between the negative and the neutral group and between the positive and the neutral group were conducted.

Second, we examined the influence of mood on the emergence of explicit knowledge by analyzing the memory tasks on a group level. To assess performance in the free recall, the largest chunk of the trained sequence that was recalled was determined for every participant. Then a mean value for each mood group was calculated and compared. For this, an ANOVA with the between-subjects factor Group (negative, neutral, and positive mood) was conducted on these data including two planned contrasts (negative vs. neutral mood group and neutral vs. positive mood group). A similar analysis was performed for the sequence production task. Here, the mean number of chunks recalled in the inclusion ("do not report the sequence") condition was subtracted from the mean number of chunks recalled in the exclusion ("report sequence") condition. This difference reflects the degree to which a person has control over reporting the trained sequence and was thus compared across the three groups, i.e., a larger difference value means more explicit knowledge. For this analysis, eight participants had to be excluded because they used keys other than the response keys (two in the negative, four in the neutral, and two in the positive mood group). Forty-four participants more (14 in the negative, 13 in the neutral, and 17 in the positive mood group), had to be excluded because they did not stick to the instructions and pressed the response buttons according to their spatial arrangement (either from right to left or vice versa) to avoid the trained sequence in the exclusion condition. Although all in all, 52 participants had to be excluded from the sequence production task, we still conducted the planned ANOVA with the between-subjects factor Mood Group (negative, neutral, and positive mood) and the same two planned contrasts as for the free recall analysis (negative vs. neutral mood group and neutral vs. positive mood group), although this large dropout rate means that the results of the sequence production task have to be treated with caution.

Third, to differentiate between implicit and explicit learners, we assessed how many participants showed hints of explicit knowledge by examining performance in the free recall and the process dissociation procedure for each individual participant. The assessment of participants as implicit or explicit learner was done based on both memory tests because they both have advantages and disadvantages and are differentially sensitive for explicit knowledge (for a review, see Cleeremans et alii, 1998). Therefore, to examine learning effects for participants without explicit knowledge, we used a conservative criterion and excluded all participants that showed explicit knowledge in one of the two memory tests. In the free recall test, participants were classified as having explicit knowledge, whenever they were able to recall five or six consecutive elements of the sequence (no participant reported four elements and the chance to correctly guess one to three elements is substantially larger (>5%) than the chance to guess four (1.7%) or more (<0.8%) consecutive sequence elements). In the sequence production task, a participant was classified as having explicit knowledge of the regularity, when the mean value of the largest chunk generated in the inclusion task was three or more elements longer than the mean value of the largest chunks generated in the exclusion task. Table 2 displays the number of participants in the respective groups that developed explicit sequence knowledge during the course of the experiment.

Fourth, to examine the influence of mood on implicit learning, we excluded explicit learners as detected by the third analysis step reported in the previous paragraph and analyzed median reaction times in the SRTT. We additionally excluded four participants (one from the negative pictures group and three from the neutral pictures group) from the analysis that committed too many errors (more than two standard deviations from the mean of the group) in responses to the repeating sequence after extensive training (in block 7 and 15). To keep the number of analyses and comparisons to a minimum, we investigated the size of the learning effects by contrasting median reaction times in the untrained sequence blocks (block 8 and 16) with the preceding trained sequence block (block 7 and 15), respectively.

Data were analyzed using t-Tests or repeated measures analyses of variance (ANOVAs) with an alpha level of .05. The Greenhouse-Geisser correction for non-sphericity was used whenever appropriate and epsilon-corrected p-values are reported together with uncorrected degrees of freedom and Greenhouse-Geisser epsilon values. For reasons of clarity, only main effects or interactions including the factors of interest are reported. Post-hoc tests were conducted using LSD test.

Mood ratings in our study might probably not be fully determined by the emotional background pictures provided during the learning paradigm but also depend on the mood in which participants arrived at the study site. Therefore, it is possible that participants arriving in a good mood were randomly assigned to the neutral or negative group and vice versa for participants arriving in a bad mood. Thus, a wide range of mood states could be present in all groups. To take this into account, we additionally calculated a linear regression model including the dummy coded variable mood group and the mood ratings as predictor variables and the size of the implicit learning effect as criterion. Because mood ratings were given only one time at the end of the learning paradigm, the learning effect within the closest proximity to the rating at the end of the experiment (untrained block 16 – trained block 15) was chosen to calculate this regression. Two participants (one from the neutral and one from the negative mood group) displayed outlier values on the variable learning effect. Because those outliers can strongly influence correlational approaches, these two participants were excluded from the regression analysis.

Materials and raw data of the study can be found at OSF (https://doi.org/10.17605/OSF.IO/3QM4U).

Results

To check whether the emotional background pictures actually induced different mood states, we first analyzed participants' mood ratings which were made immediately after the sequence learning task. Overall, all groups were in a mildly positive mood, as indicated by mean values above five with a possible range of values from zero meaning negative mood to 10 meaning positive mood (see Table 2). The planned contrasts revealed that the negative mood group was in a less positive mood than the neutral group ($t(147)= 1.90$, $p <.05$). There was no difference between the positive and the neutral group ($p= .23$).

Table 2. Results of the Rating Scales.

	Groups		
	Negative Backgrounds	Neutral Backgrounds	Positive Backgrounds
Ratings (*SD*)	6.1 (0.2)	6.7 (0.2)	6.4 (0.2)
al Ratings (*SD*)	6.3 (0.3)	7.2 (0.3)	6.7 (0.3)
ved Emotionality of ;round Pictures (*SD*)	3.5 (0.4)	5.4 (0.6)	7.6 (0.5)

Next, we checked for differences in the three groups' arousal. The planned contrasts for arousal found no group differences (all *p*-values >= .25). All groups displayed a mean arousal, as indicated by mean values around four with a possible range of values from zero (no arousal) to ten (maximum arousal).

Finally, the ratings to the question of whether and how much the background pictures induced positive or negative feelings during the experiment were analyzed. Not all participants provided a response to this question. Especially in the neutral group, half of the participants preferred not to respond, probably because there were no emotions induced (negative group: n=43; neutral group: n=25; positive group: n=37). The planned contrasts revealed that the negative mood group actually experienced the background pictures as more negative than the neutral group ($t(102)= 2.58$, $p <.01$) and the positive group experienced the background pictures as more positive than the neutral group ($t(102)= 2.91$, $p <.01$). Ratings were made on a continuous scale ranging from zero (strong negative feelings) to ten (strong positive feelings).

To assess performance in the free recall (see Figure 2a), an ANOVA with the factor Group (neutral, positive, negative) was calculated on the largest chunk size recalled for the trained sequence. This ANOVA resulted in a main effect of Group ($F_{(2,147)}$= 3.4, p <.05, ηp^2= .04). Planned contrasts revealed that larger chunk sizes were recalled in the group with negative background pictures than in that with neutral pictures (t(147)= -2.6, p <.01). There was no difference between the group with neutral and with positive pictures (p= .09).

The analogous analysis was done on the performance in the sequence production task as measured in the difference between the mean number of chunks reported in the inclusion and the exclusion condition (see Figure 2b). This ANOVA did, however, not result in a significant main effect for Group nor did the planned contrasts reveal any significant differences (all p-values >.36).

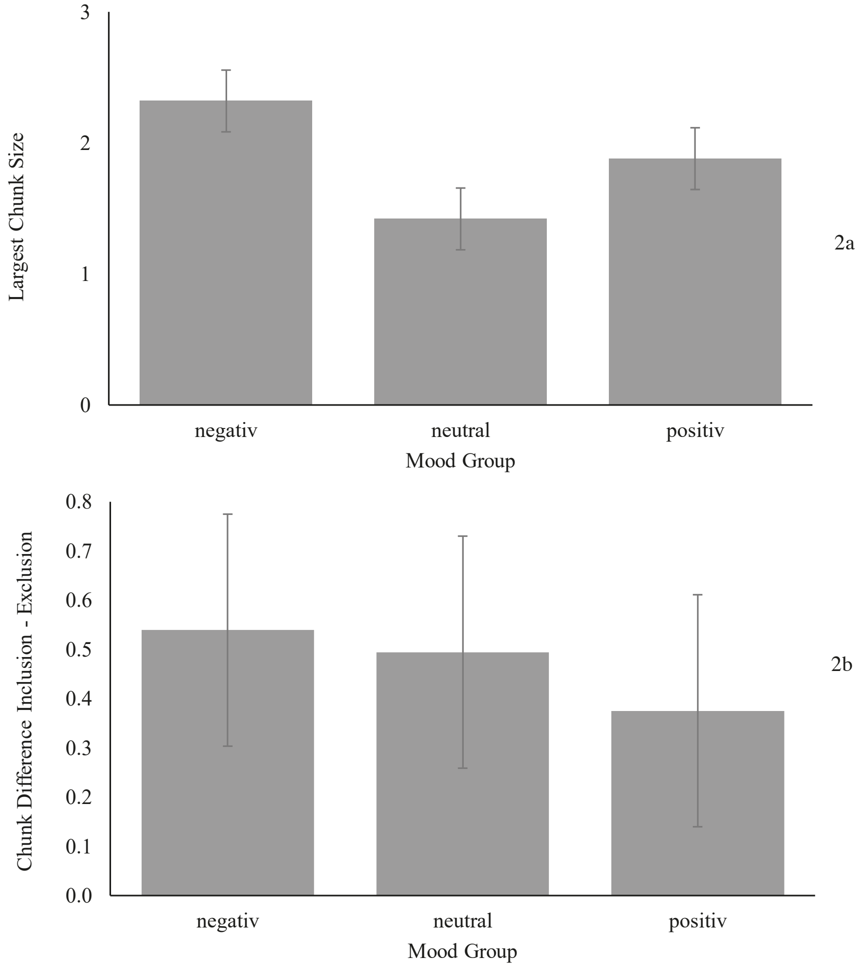

Figure 2. Differences in explicit knowledge between the three mood groups as indexed by a) the size of largest chunk recalled during the free recall and b) the mean difference between the two conditions of the process-dissociation procedure.

Table 3 displays the number of participants in the respective groups that developed explicit sequence knowledge during the course of the experiment. These participants were excluded to examine the influence of mood on implicit learning. Median reaction times over the course of the experiment for all participants that were classified as having no explicit sequence knowledge can be found in Figure 3.

Table 3. Number of participants with explicit knowledge in the Free Recall or the Process Dissociation Procedure (PDP).

	Groups		
	Free Recall	PDP	Free Recall and/or PDP
Negative Backgrounds	6	2	6
Neutral Backgrounds	2	1	3
Positive Backgrounds	5	1	6
Total	13	4	15

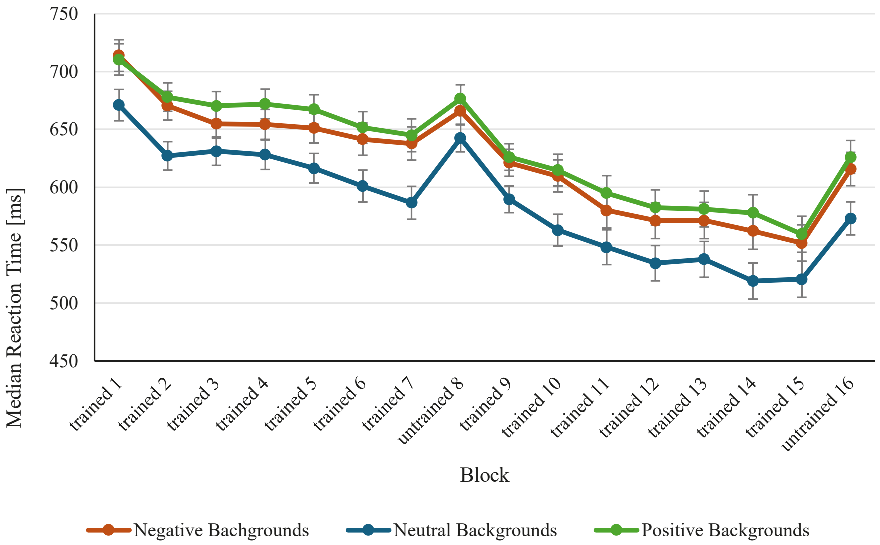

Figure 3. Median reaction times of the negative, neutral, and positive mood groups across the 16 blocks of the experiment. Whiskers denote standard errors of the *M*.

To examine the influence of mood on implicit learning, an ANOVA with the factors Group (neutral, positive, negative), Experiment Half (first, second), and Sequence Type (trained, untrained) was calculated on the median reaction times. This analysis resulted in a main effect of Group ($F(_{2,128})$= 3.7, p <.05, ηp^2= .06), with *post-hoc* tests showing faster reaction times in the neutral mood group than in the positive (*M* difference= 46; p=< .05) and negative (*M* difference=37; p=<.05) mood group. There were also main effects for Experiment Half ($F(_{1,128})$= 213.2, p <.001, ηp^2= .63), indicating faster reaction times in the second half of the experiment, and Sequence Type ($F(_{1,128})$= 145.6, p <.001, ηp^2= .53), reflecting faster reaction times in the trained than the untrained sequence, i.e., an implicit learning effect. Additionally, it yielded interactions between Experiment Half and Sequence Type ($F_{(1,128)}$= 11.3, p <.001, ηp^2= .08) and between Group, Experiment Half, and Sequence Type ($F_{(2,128)}$= 3.7, p <.05, ηp^2= .06).

To explain these effects and interactions, we calculated separate ANOVAs with the factors Experiment Half and Sequence Type for each group. For all groups, this resulted in main effects for Experiment Half (neutral: $F_{(1,43)}$= 42.6, p <.001, ηp^2= .50; positive: $F_{(1,43)}$= 111.2, p <.001, ηp^2= .72; negative: $F_{(1,42)}$= 104.0, p <.001, ηp^2= .71), indicating that reaction times were faster in the second as compared to the first half, and Sequence Type (neutral: $F_{(1,43)}$= 44.5, p <.001, ηp^2= .51; positive: $F_{(1,43)}$= 58.6, p <.001, ηp^2= .58; negative: $F_{(1,42)}$= 46.4, p <.001, ηp^2= .53), reflecting the fact that reaction times were larger for the untrained than for the trained sequence. For the emotional groups, the interaction between Experiment Half and Sequence Type was also significant (positive: $F_{(1,43)}$= 10.0, p <.01, ηp^2= .19; negative: $F_{(1,42)}$= 18.5, p <.001, ηp^2= .31). This interactions were due to faster reactions to trained than untrained sequence stimuli in all conditions (positive group, first half: $F_{(1,43)}$=17.4, p <.001, ηp^2= .29; positive group, second half: $F_{(1,43)}$= 51.8, p <.001, ηp^2=.55; negative group, first half: ($F_{(1,42)}$= 13.5, p <.001, ηp^2= .24; negative group, second half: ($F_{(1,42)}$= 60.5, p <.001, ηp^2= .59), but larger effects in the second halves as compared to the first halves, as can be inferred from the effect sizes.

Because mood ratings also depend on the mood in which participants arrived at the study site, we additionally calculated a linear regression analysis including the dummy coded variable mood group, the mood rating as predictor variables, and the size of the implicit learning effect as criterion. The overall regression model did not yield statistically significant effects (p= .65). Neither Mood Group nor Mood Rating significantly predicted implicit learning (all p-values >= .33; see Figure 4).

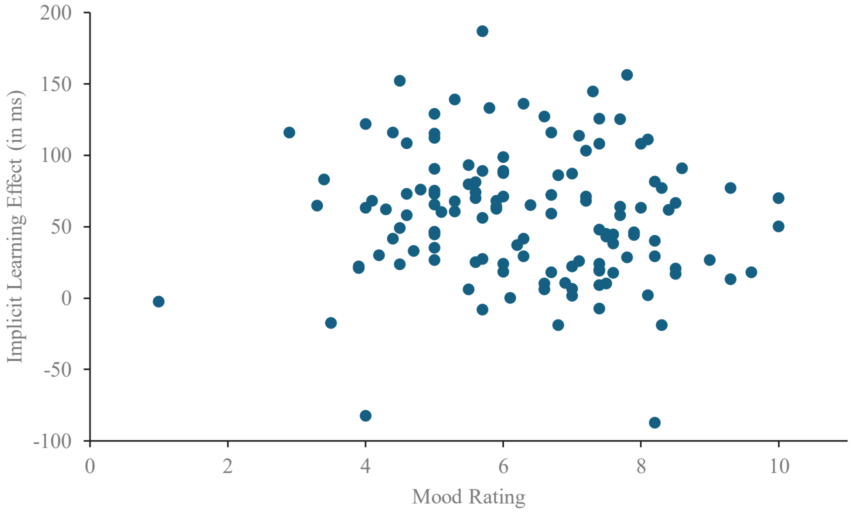

Figure 4. Scatterplott for mood rating and implicit learning effect.

Discussion

The aim of the present study was to investigate whether different mood states would influence implicit learning and the emergence of explicit knowledge. For this reason, participants conducted an incidental sequence learning task. In order to ensure that the mood induction would be in effect over the whole duration of the learning paradigm, mood was induced via emotional background pictures. Mood states were rated by the participants immediately after the end of the learning paradigm and explicit knowledge was probed by a semi-structured interview and a process-dissociation procedure.

The analyses of the rating scales showed that overall, all groups were in a mildly positive mood. While there were no mood differences between the positive and the neutral group, the negative mood group was in a less positive mood than the neutral group. This means that although the negative group was in a more negative mood than the other groups, the background pictures did not induce clearly separable negative, neutral, and positive mood states in the three groups. A reason for this could be that participants were randomly assigned to one of the three mood groups, thus it might have happened that participants in a positive mood were assigned to one of the other groups and vice versa. However, participants also indicated that the three types of background pictures were clearly experienced as emotionally different. Participants from the negative mood group rated the background pictures as emotionally negative, participants from the neutral group rated the pictures as neutral, and participants in the positive mood group rated the pictures as positive. So, all in all, we assume that we were at least successful in changing participants' mood states in the intended directions. The second analysis suffers from the fact that not all participants provided an answer to this rating. But because this was mainly due to no answers in the neutral mood group, this could indicate that no strong positive or negative feelings were induced in the neutral mood group. The rating scales did not reveal differences in the three groups' arousal, so any differences in implicit learning effects or in the formation of explicit knowledge between the groups cannot be attributed to differences in arousal.

The results of the free recall demonstrated that participants from the negative mood group were able to recall larger chunks of the repeating sequence than participants from the positive and neutral mood group. There was no difference between the group with neutral and with positive pictures, however, these two groups did also, according to their mood ratings, not differ in reported mood. This finding is in accordance with our hypothesis and shows that participants in a worse mood acquire more explicit, verbalizable sequence knowledge than participants in a better mood.

The analogous analysis was done on the performance in the sequence production task as measured in the difference between the mean number of chunks reported in the inclusion and the exclusion condition. This measure reflects the fact that more control over the acquired knowledge is necessary in the case of generating a sequence that is different from the repeated sequence (exclusion) than in the case of producing this repeated sequence or one that is similar to it (inclusion). Usually, explicit sequence knowledge is necessary to be able to produce different sequences in the two conditions. This measure of explicit knowledge did, however, not result in significant group differences. The reason for this might be that we had to exclude a good third of our participants because they did not follow the instructions. Eight participants used keys other than the response keys and 44 participants pressed the response buttons according to their spatial arrangement (either from right to left or vice versa). Both was done to securely avoid typing the trained sequence in the exclusion condition but is not necessarily based on conscious knowledge of what sequence to avoid. So it seems that either the sequence production task was too difficult for a lot of participants, or it was not optimally instructed. Either way, the results of this task should be treated with caution because the task probably did not measure explicit knowledge in a reliable and valid way.

In the sequence learning task, in which only participants were included that did not show any hints of explicit sequence knowledge in the free recall or the production task, reaction times were faster in the second as compared to the first half of the learning paradigm. This effect demonstrates general learning effects, like getting used to executing the task and probably also learning the repeating sequence. Because both effects are inseparably intertwined in this reaction time measure, one cannot unequivocally infer implicit sequence learning from it. However, our data additionally showed that reaction times were generally larger for the untrained than for the trained sequence. Thus, we can infer that the repeating sequence was learned implicitly.

This implicit learning effect was present in all groups and both experimental halves, but in the first half it was smaller for the negative and the positive mood group than for the neutral mood group. This finding speaks against the expectations derived from the mood-as-information hypothesis that larger implicit learning effects should be found in the positive mood group because a positive mood leads to more bottom-up, heuristic processing. This finding is also strengthened by the results from the regression analysis that did neither find a relationship between mood group and the size of the implicit learning effect nor between reported mood and the implicit learning effect. Our results do not mean that different mood states cannot change the processing style that is used to process the information at hand. In contrast, there is ample evidence that this can be the case in several domains including research on memory, semantical priming, or person perception (for a review, see Bless & Fiedler, 2006). However, from our data we cannot infer that positive mood strengthens implicit learning of sequential regularities.

When considering the neurobiological mechanisms of implicit learning, it might even be plausible to assume that it should be rather independent of mood influences. Implicit learning can be thought of as a complex form of priming (Becker *et alii*, 1997; Cleeremans *et alii*, 1998) which takes place automatically or rather as a by-product while stimuli are repeatedly processed, and motor responses are executed. According to Reber (2013), implicit learning is a pervasive mechanism of neural plasticity which leads to improved performance via encoding the statistical regularities of the environment or the task at hand caused by repetition. Evidence for this idea comes from studies showing that activation correlating with implicit learning is usually found in those brain regions that are necessary to perform the task at hand, while the medial temporal lobes that are responsible for explicit memory, are not involved (Reber, 2013; Han *et alii*, 2022). By this, implicit learning might represent such a basic mechanism of learning via neuronal plasticity changes that cannot easily be influenced by different processing styles.

Instead of finding better implicit learning in the positive mood group, we found a smaller learning effect in the first half of the sequence learning paradigm for the negative as well as the positive mood group, i.e., implicit learning happened more slowly in these two groups. This finding might reflect the fact that the emotional background pictures captured attention in both of these groups which might have led to impaired learning. This finding is in line with earlier research demonstrating that implicit learning can be modulated by attentional processes (Gaschler, Frensch, Cohen, & Wenke, 2012; Haider, Eberhardt, Esser, & Rose, 2014; Tanaka *et alii*, 2008). At first glance, this argument might be at odds with the above argument that implicit learning as a fundamental processing mechanism cannot be changed by different processing styles. However, no matter what the processing style, be it analytic or heuristic, the task is processed with a certain degree of attention. However, when attention is diverted from the task, the intensity with which it is processed becomes less and this, in turn, could lead to slower changes in plasticity. This interpretation is also consistent with the generally slower reaction times in the two mood groups.

The finding that the neutral group is faster than the two mood groups in all blocks, even those that contain the un-trained sequence, also opens up another possible interpretation. Namely, the reaction time increase from trained to untrained sequence might be influenced by general performance differences. For instance, in the positive and the negative condition participants might spent more time on the background picture and the SRTT stimulus and respond more slowly. Therefore, potential response activation stemming from sequence knowledge might not play out fully. So potentially, implicit learning might even be present in the first learning half to a similar extent as in the second half, yet it does not completely manifest and translate into reaction time benefits/costs as strongly as in the neutral condition (Hoyndorf & Haider, 2009).

One limitation of the present study design, which is a strength at the same time, is that mood was assessed only one time after the sequence learning task had been finished. The problem of this single assessment of mood is that we do not exactly know whether participants' mood was actually changed via the mood induction method. For this, one would have needed to assess mood pre and post the sequence learning paradigm in which the mood induction was embedded. We decided to not assess mood before the mood induction and sequence learning because it could have drawn the participants' attention to the fact that mood was an important aspect of the study. In this case, observation of the own mood state as well as emotion regulation processes counteracting the mood induction would most probably have taken place. Finding a relationship between mood and implicit learning would have been impeded. What is more, to counteract the shortcoming of only one mood assessment, we assessed mood immediately after measurement of the learning effect (which took place at the end of the sequence learning paradigm) and in addition to examining the effect of the mood induction (the manipulation) on implicit learning, we also investigated the relationship of the mood ratings on implicit learning. Thus, if mood ratings are an acceptable measure of participants' actual mood (no matter whether induced by the study protocol or stemming from a different source), we can infer that mood was not related to implicit learning in our study.

Another limitation is, that one might argue that we did not find an effect of positive mood on implicit learning because the background pictures we used were not successful in inducing the intended mood states. However, there are several arguments speaking against this idea. First, the background pictures were rated as clearly reflecting negative emotional content in the negative mood group, neutral emotional content in the neutral mood group, and positive emotional content in the positive mood group. Second, although the negative mood group on average did not report values supporting a negative mood, this group had lower mood values indicating that it was on average in a worse mood than the other two groups. Also, this worse mood was related to the emergence of more explicit sequence knowledge in the free recall, thus it most likely influenced participant's processing style to a more hypothesis-driven, analytical style which in turn led to the detection of the sequence regularity. Third, the neutral and the positive mood group both reported being in a comparable positive mood state, so it is possible that positive and neutral pictures both induced a positive mood. Still, we did not find that these two groups showed enhanced implicit learning as compared with the negative mood group. Fourth, because it might be possible that the mood ratings, in addition to depending on the mood induction, were also influenced by the mood in which participants arrived at the study site, we analyzed whether the reported mood across all groups could predict the size of the implicit learning effect. However, this was not the case. The mood participants reported immediately after the learning paradigm was not related to implicit learning. Nevertheless, future research could use a different type of mood induction and try to replicate the present findings. We chose background pictures during the learning task, because common mood inductions, like showing video clips or pictures before the study, have the problem that the induced mood is usually neutralized rapidly and thus does not influence the processes under examination for the whole time it takes to assess them. Another possibility for future studies that could also be used during the whole time the learning task lasts and thus circumvent the fleeting nature of prior mood inductions, could be to play mood-inducing music while participants are conducting the learning task.

The present study aimed at examining the influence of mood on implicit sequence learning and the formation of explicit knowledge. In line with the affect-as-information hypothesis assuming a more analytic processing style during negative mood states, we found that a less positive mood resulted in more explicit sequence knowledge. In contrast, our expectation that positive mood would enhance implicit learning via a more relational processing style was not confirmed.

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