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Effects of Material Emotional Valence on the Time Course of Massive Repetition Priming

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Abstract Learning through repetition is a fundamental form and also an effective method of language learning critical for achieving proficient and automatic language use. Massive repetition priming as a common research paradigm taps into the dynamic processes involved in repetition learning. Research with this paradigm has so far used only emotionally neutral materials and ignored emotional factors, which seems inappropriate given the well-documented impact of emotion on cognitive processing. The present study used massive repetition priming to investigate whether the emotional valence of learning materials affects implicit language learning. Participants read a list of Chinese words and made speeded perceptual judgments about the spatial configuration of the two characters in a word. Each word was repeated 15 times in the whole learning session. There were three types of words, negative, positive, or neutral in their emotional valence, presented in separate blocks. Although similar levels of asymptotic performance were reached for different valence conditions showing comparable total effects of learning, learning of the positive words was found to be associated with fewer plateaus of shorter durations and to reach saturation earlier, compared with neutral and negative words. The results showed for the first time that the emotional valence of learning materials has significant effects on the time course of learning so that positive materials are learned faster and more efficiently, relative to negative and neutral materials.

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The study indicates the importance to explicitly consider the role of emotional factors in implicit language learning research.

Keywords Language learning · Emotion · Modulation · Massive repetition priming

Introduction

Skill learning, also called skill practice, is an omnipresent and pervasive form of learning (Colagrosso et al. 2004). Language learning is one type of skill learning particularly important to humans. For example, language learning is a crucial component of language acquisition and language development. As we have more experience in reading, writing, and speaking, our linguistic behaviors become less error prone and more fluent, rapid, and robust against irrelevant distractions (Ofen-Noy et al. 2003). Other than explicit learning, language learning can also be studied implicitly, for example, using the priming paradigm (Colagrosso et al. 2004). In a priming task, participants are not told and hence not aware of the relationship between two learning periods so that there is no intentional recall of previous learning events during task performance in latter periods.

One specific priming paradigm is massive repetition priming where stimuli (e.g. words) are repeatedly presented many times (usually around 10–30 presentations) in a learning session. This paradigm has been much used to study the dynamic processes during language learning (e.g. Gatbonton and Segalowitz 1988; Grant and Logan 1993; Hauptmann and Karni 2002; Salasoo et al. 1985), given that in this paradigm unpredictable target presentation can effectively minimize intentional recall and that maximal target-prime similarity usually produces strong priming effect. For example, using a word identification learning task, Salasoo et al. (1985) showed that repetition priming for word and pseudowords was cumulative so that identification threshold decreased continuously over 30 presentations. Grant and Logan (1993) also reported a buildup of repetition priming in a lexical decision task with 16 repeated presentations. Gatbonton and Segalowitz (1988) showed that, with sufficient repetitions, the automaticity component of fluency in second language production can be developed in a wholly communicative context where learning was not explicitly required.

However, language learning studies have so far ignored emotion. For example, the above-mentioned studies all used emotionally neural materials. Much evidence in the rapid-growing field of affective neuroscience research has indicated the importance of emotional factors in cognitive processing (Pessoa 2008). Emotion is considered a stimulator and organizer for cognition involved in all aspects of behavior, social interaction and development (LeDoux 1996), to which language learning should be no exception. In fact, with a model interweaving the emotional dimension with the cognitive dynamics of the learning process, Kort and Reilly (2002) demonstrated that learning models without emotion factors would have severe limitations.

As one first attempt to address the role of emotion in the dynamic course of language learning, the present study used the massive repetition paradigm to investigate whether the emotional valence of learning materials has any effect on implicit language learning. In our task, participants were visually presented with a series of words and asked to make judgment about the spatial configuration of each word. These words could be positive, negative, or neutral in their emotional valence and were repetitively presented multiple times.

Terminology and Definitions

For easy understanding, below we give the definition of several phenomena and laws involved in massive repetition priming studies.

In the formulas below n indicates the n-th presentation of a certain stimulus, $t_i (i = 1, 2, 3, \ldots, n)$ indicates the time point when a stimulus was presented for the i-th time, and y_i indicates the mean reaction time (RT) for all participants at this time point.

The Negative Power Curve

The negative power function law captures the general observation that performance improves with repetition but the degree of improvement decreases over time (Logan 1990). The following equation describes a negative power function:

$$RT = A \cdot T^{-B} \tag{1}$$

where RT refers to reaction time for the T-th presentation of the repeated item, A is a parameter that approximates the reaction time for the first presentation, and B is another parameter that determines the steepness of the power function.

The Improvement Period of Skill

The practice or learning effects occur when there is a gradual decrease in reaction time as the number of repetition increases. The improvement period of skill is the time interval when reliable practice effects are found consecutively. Mathematically, the improvement period is the time segment during certain two consecutive presentations, where reaction time of the latter presentation is significant shorter than the former presentation ($p < 0.05$). The following formula describes the improvement periods:

$$I = \{[t_i, t_{i+1}] | y_{i+1} < y_i\} \qquad (i = 1, 2, \ldots, n-1) \tag{2}$$

where I refers to the set of all improvement periods in the whole process. Note that '<' means 'significantly shorter at the statistical threshold of $p < 0.05$'.

The Plateau Phenomenon

The plateau phenomenon has been found in many types of learning. It refers to the period when the skill improvement stops temporally, during which performance does not increase and reaction time does not decrease even though people exercise ceaseless (Franks and Wilberg 1982). Mathematically, a plateau period refers to a time segment in which reaction times for latter presentations are not significantly shorter than the first presentation ($p < 0.05$). We constructed the following formula to describe the plateau periods:

$$\begin{aligned} P = \{[t_i, t_{i+k}] | (y_i \le y_{i+1}) \& (y_i \le y_{i+2}) \& \ldots \& (y_i \le y_{i+k}) \& (y_i > y_{i+k+1})\} \\ (i = 1, 2, \ldots, n-2; k = 1, 2, \ldots, n-2) \end{aligned} \tag{3}$$

where P refers to the set of all plateau periods in the whole session. Note that the operators '$\le$' and '$>$' indicate relationship at the given statistical significance level of $p < 0.05$.

The Saturation Phenomenon

The saturation phenomenon depicts the steady state when performance does not increase and reaction time does not decrease any more even though people keep on exercising (Lewis and Ellis 2000; Peterka and Benolken 1995). Contrary to the plateau phenomenon, which is a temporal stagnation, saturation is a state that will persist permanently. Mathematically, the saturation period refers to a time period after a certain time point (called saturation point) since then reaction time will no longer decrease, i.e. reaction time for all the following presentations does not differ significantly from the saturation point. We constructed the following formula to describe the saturation period:

$$S = \{[t_i, t_n] | (y_i = y_{i+1}) \& (y_i = y_{i+2}) \& \ldots \& (y_i = y_n)\} \qquad (i = 1, 2, \ldots, n-1) \quad (4)$$

where S refers to the set of the saturation period. Note that S has only one element as there is only one saturation period in the whole learning session.

Method

Participants

A total of 26 college students (20 female, 6 male, mean age = 21.7 years, age range = 19–27 years) from Beijing Normal University (Beijing, China) participated in this experiment for monetary compensation. All were right-handed native Mandarin Chinese speakers. Written informed consent was obtained from each participant following a research protocol approved by the Institutional Review Board of the Beijing Normal University.

Materials and Design

The stimuli included negatively, positively, and neutrally valenced two-character Chinese words. There were a total of 48 words, 16 for each category, selected based on rating results from 20 college students (who were different from the participants described above) on a 9-point Likert scale (1: strongly negative; 5: neutral; 9: strongly positive). The mean rating values were 2.07, 5.00, and 7.80 for the negative, neutral and positive words, respectively, differing from each other significantly ($ps < 0.001$). Word frequency (mean = 36.3, range = 2–330 per million, *Modern Chinese Frequency Dictionary* 1986) and stroke numbers (mean = 18.5, range = 11–27) were also matched across the three categories of words.

The task made use of a characteristic of the pictographic Chinese writing system where characters are composed of radicals and can take different spatial configurations. Some characters have only one radical (e.g. 友). Some others have two radicals that can be positioned from left to right (e.g. 愉), or from top to bottom (e.g. 毒), or with one surrounding the other (e.g. 阅). Our participants were asked to compare the two characters in each word and decide whether or not they were of the same spatial configuration. For half of the words in each category, the two characters were of the same configuration (e.g. '愉快' , meaning *happy*), and for the other half, the two characters were of different configurations (e.g. '狠毒', meaning *vicious*). The design was a within-subject design with two factors, including word valence (negative, neutral, and positive) and number of presentations (1, 2, 3, …, 15). Each word was randomly presented 15 times, considered sufficient to examine the entire process of massive repetition priming in the literature (e.g. Grant and Logan 1993; Lewis and Ellis 2000; Salasoo et al. 1985).

The same word would not be consecutively presented more than 2 times and there could be at most 10 words between two successive repetitions of the same word. Words of different valences were blocked and presented in separate sessions to avoid interference between different emotions. As in other massive repetition priming studies (e.g. Lewis and Ellis 1999), each word was both the concurrent target stimulus and a prime stimulus for its following presentations.

Procedure

The experiment was conducted in a lightproof and soundproof room. The apparatus for the experiment consisted of a keyboard and a CRT, a Windows PC that controlled stimulus presentation and response recording using the DMDX software with millisecond timing accuracy (http://www.u.arizona.edu/~jforster/dmdx.htm).

Participants were seated in front of the CRT at a distance of about 50 cm. All prompts and words were shown on the CRT and participants input their answers with the keyboard. For each trial, a '*' was presented for 500 ms, followed by a word shown for 190 ms. Participants were asked to react as accurately and quickly as possible within a 2,000 ms response window. They should press the left or the right 'Shift' key if they judged the configurations of the two characters to be the same or different. The next trial started following the response. There were six sessions for the whole experiment, two for each valence category. The session orders were counterbalanced across subjects. Participants did a short practice session before the formal sessions and there was a brief break between two sessions.

Results

Incorrect trials were excluded from the reaction time analyses, along with outlier trials where response latencies were beyond three standard deviations from the mean. The standard deviation was based on each participant's data individually and also separated for each of the 15 presentations. The discarded trials accounted for less than 2% of the total number of trials.

The Fitted Negative Power Curve

The mean reaction time for each presentation in all three valence conditions are showed in Table 1; Fig. 1.

Regression analysis showed that the relationship between the number of presentations and the corresponding reaction time fitted negative power functions. The global fit of the analysis was significant (negative: $R^2 = 0.256, F(1, 388) = 133.70, p < 0.001$; neutral: $R^2 = 0.266, F(1, 388) = 140.51, p < 0.001$; positive: $R^2 = 0.227, F(1, 388) =$

Table 1 Mean reaction times (in ms) for each presentation for the negative, neutral and positive conditions

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Negative word	820	706	648	616	610	630	591	594	588	583	588	591	571	569	573
Neutral word	796	742	676	649	621	615	617	607	581	585	571	592	569	586	572
Positive word	786	717	676	648	637	637	619	595	593	587	587	593	590	588	582

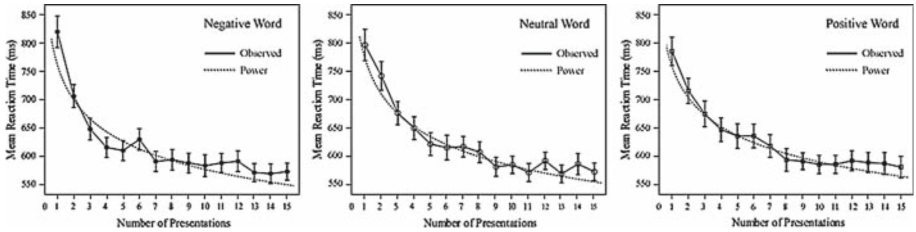

Fig. 1 Mean reaction times in character spatial configuration judgment plotted against the number of presentations. *Dashed lines* indicate the best fit negative power curves for each condition. *Error bars* show standard errors. The *left*, *middle* and *right panels* correspond to the negative, the neutral, and the positive conditions, respectively

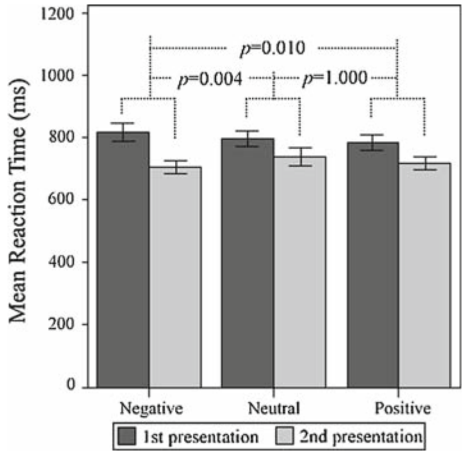

Fig. 2 Illustration of the first repetition priming effect measured as the reaction time decrement in the second presentation relative to the first presentation. The *p* values indicate statistical significance of the priming effect in pair-wise comparisons between the negative, neutral, and positive conditions. *Error bars* show standard errors

113.93, $p < 0.001$). According to formula (1), the equations of each condition were determined as follows:

Negative condition: $RT = 756.52 \cdot T^{-0.117}$
Neutral condition: $RT = 771.52 \cdot T^{-0.122}$
Positive condition: $RT = 758.56 \cdot T^{-0.109}$

The Reaction Time for the First Presentation

The reaction time for the first presentation was not statistically different across the three valence conditions (negative: 820 ms, neutral: 796 ms, positive: 786 ms; one-way repeated-measure ANOVA, $F(2, 50) = 1.35$, $p > 0.2$; see Fig. 2). There was a trend that response to the negative words were slower than the positive ones (pair-wise *t*-test, $p = 0.18$).

The First Repetition Priming Effect

The first repetition priming effect refers to the reaction time decrement in the second presentation of a word relative to its first presentation. A 2 (presentation time: first, second) × 3 (word valence: negative, neutral, positive) ANOVA on reaction time data revealed a significant main effect of presentation time ($F(1, 25) = 85.38$, $p < 0.001$). There were first repetition priming effects for all conditions (negative: 114 ms, neutral: 54 ms, positive: 69 ms;

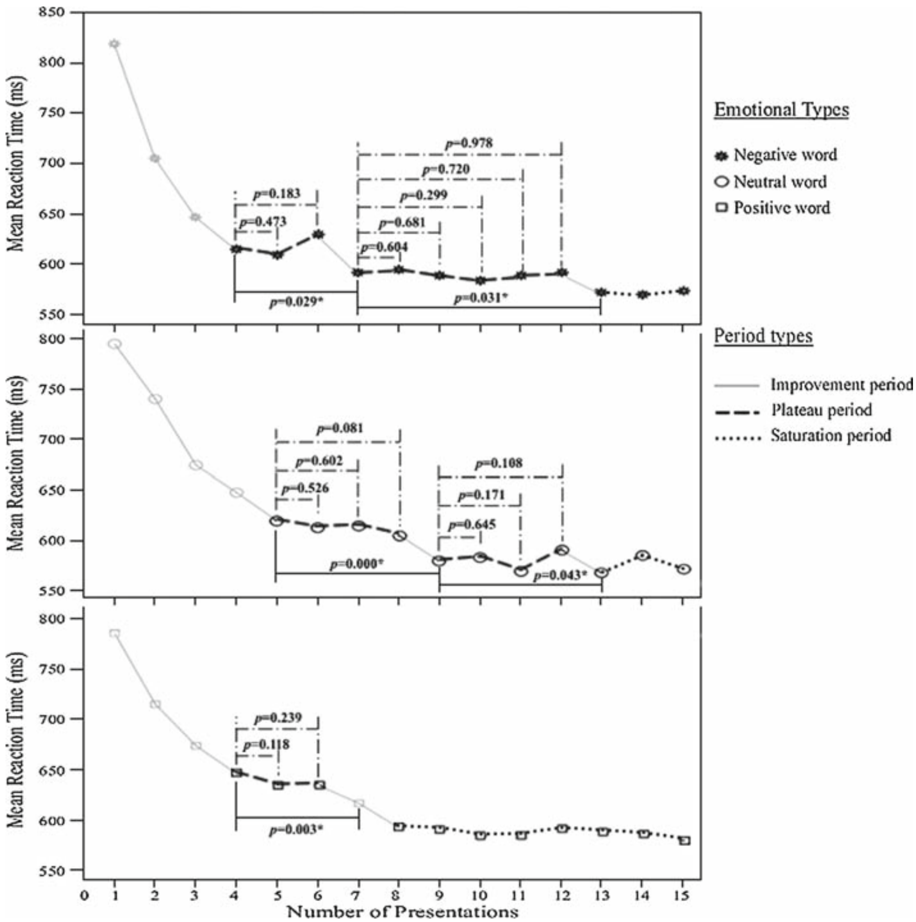

Fig. 3 Illustration of improvement periods, plateau periods, and saturation period during massive repetition priming for the negative (*top panel*), neutral (*middle panel*), and positive (*bottom panel*) conditions. *Gray lines* indicate improvement periods, *broken lines* indicate plateau periods, and *dashed lines* indicate saturation period. p values indicate statistical significance for pair-wise comparisons between the start of each plateau period and the rest time points

see Fig. 2). Pair-wise comparisons showed a significant difference between the negative and neutral conditions ($p < 0.005$), between the negative and positive conditions ($p = 0.01$), but not between the positive and neutral conditions ($p > 0.9$).

The Improvement Periods

The improvement periods were determined according to formula (2) and shown as gray lines in Fig. 3.

For the negative condition, there were three consecutive improvement periods: $[t_1, t_4]$ (i.e. the time between the 1st and 4th presentations), $[t_6, t_7]$, and $[t_{12}, t_{13}]$, or mathematically,

$$I_{neg} = [t_1, t_2] \cup [t_2, t_3] \cup [t_3, t_4] \cup [t_6, t_7] \cup [t_{12}, t_{13}]$$

For the neutral condition, there were three consecutive improvement periods: $[t_1, t_5]$, $[t_8, t_9]$, $[t_{12}, t_{13}]$, or mathematically,

$$I_{neu} = [t_1, t_2] \cup [t_2, t_3] \cup [t_3, t_4] \cup [t_4, t_5] \cup [t_8, t_9] \cup [t_{12}, t_{13}]$$

For the positive condition, there were only two consecutive improvement periods: $[t_1, t_4]$ and $[t_6, t_8]$, or mathematically,

$$I_{pos} = [t_1, t_2] \cup [t_2, t_3] \cup [t_3, t_4] \cup [t_6, t_7] \cup [t_7, t_8]$$

The Plateau Phenomenon

The plateau periods were determined according to formula (3) and shown as black broken lines in Fig. 3.

For the negative condition, the plateau periods occurred from the 4th to 6th presentations, and the 7th to 12th presentations, or mathematically,

$$P_{neg} = [t_4, t_6] \cup [t_7, t_{12}]$$

For the neutral condition, the plateau periods occurred from the 5th to 8th presentations, and the 9th to 12th presentations, or mathematically,

$$P_{neu} = [t_5, t_8] \cup [t_9, t_{12}]$$

For the positive condition, the plateau period occurred from the 4th to 6th presentations, or mathematically,

$$P_{pos} = [t_4, t_6]$$

The Saturation Phenomenon

The saturation periods were determined according to formula (4) and shown as black dashed lines in Fig. 3.

For both the negative and the neutral conditions, the saturation period occurred from the 13th presentation, i.e.

$$S_{neg} = [t_{13}, t_{15}]$$
$$S_{neu} = [t_{13}, t_{15}]$$

For the positive condition, the saturation period occurred from the 8th presentation, i.e.

$$S_{pos} = [t_8, t_{15}]$$

The Final Effect of Learning and the Total Repetition Priming Effect

After massive repetition, performance in all three valence conditions reached saturation, and the final effect of learning, indexed by the reaction time for the last presentation, was comparable across conditions (negative: 573 ms, neutral: 572 ms, positive: 582 ms; $ps > 0.9$ for all pair-wise comparisons; see Fig. 4).

The total repetition priming effect refers to the reaction time decrement in the last presentation of a word relative to its first presentation. A 2 (presentation time: first, last) × 3 (word valence: negative, neutral, positive) ANOVA on reaction time data revealed a significant main effect of presentation time ($F(1, 25) = 167.85$, $p < 0.001$). There were total repetition priming effects for all three conditions (negative: 247 ms, neutral: 224 ms, positive:

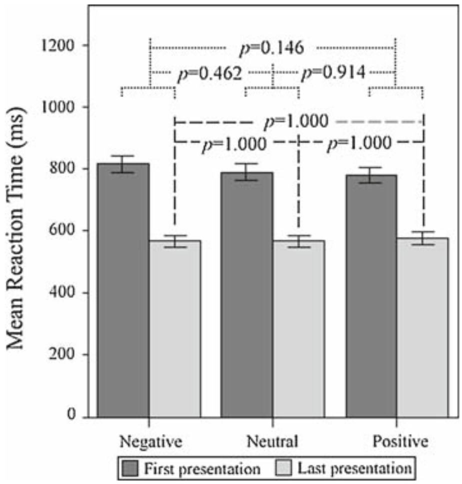

Fig. 4 Illustration of the final effect of learning (reaction time for the last presentation) and the total repetition priming effect (reaction time decrement for the last presentation relative to the first presentation). *p* values indicate statistical significance of the two effects in pair-wise comparisons between the negative, neutral, and positive conditions. *Error bars* show standard errors

204 ms; see Fig. 4). Pair-wise comparisons showed no significant differences across conditions ($ps > 0.1$).

Discussion

Repetition priming is a typical form of learning and considered among the first few steps on the way to language automaticity (Gatbonton and Segalowitz 1988). Repetitious practice is also one of the fundamental and most effective methods in language learning where, for example, words are read, listened, spoken, and written many times for fluent and accurate language performance.

In the general context of recent progress in cognitive neuroscience emphasizing the interaction between emotion and cognition (e.g. Pessoa 2008), the present study investigated whether the emotional valence of learning materials affected the dynamic processes of language learning as measured with massive repetition priming. Our participants read a list of two-character words each presented repetitively many times and compared the spatial configurations of the two constituent characters. The critical manipulation was that some words carried emotional valence (positive or negative) while others were emotionally neutral.

Although valence was defined based on the semantic meaning of the words (i.e. the meaning of the word *death* needs to be accessed first before one knows it is emotionally negative), the task involved only shallow processing and the semantic meaning of the words was irrelevant to proper task performance. Therefore, any emotional effects on learning would tap into the automatic and implicit processes we intended to study with the priming paradigm.

For the control condition involving emotionally neutral words, reaction time across the 15 repetitive presentations showed the typical negative power function as documented in other massive priming studies using neutral materials (Grant and Logan 1993; Hauptmann and Karni 2002; Lewis and Ellis 1999; Salasoo et al. 1985). For example, Grant and Logan (1993) used a lexical decision task with 16 repetitions and Hauptmann and Karni (2002) a letter enumeration task with 10 repetitions. That is, response became faster as the number of repetitions increased, however the performance improvement was more dramatic in the very first few repetitions but gradually tapered off before reaching a saturation point where additional repetitions would not lead to significant decrease in reaction time. This, on the one hand, corroborated the effectiveness of repetition in language learning, and on the other hand indicated that learning methods based on pure repetition are limited in that more repetitions may not always improve learning.

As we tested only 15 repetitions and used only reaction time as an index for effects of learning, we cannot claim that no further learning is possible with more repetitions (like a 100) or that when reaction time saturates, there are no other forms of learning which may not be reflected by reaction time. Our conclusion may not apply to other situations involving different formats of learning. For example, it has been found that further performance improvement can occur if a delay is introduced after an asymptote (e.g. Grant and Logan 1993; Salasoo et al. 1985).

Regarding our main interest, the results showed similar negative power functions of learning for both the positively and negatively valenced words, suggesting the same underlying mechanisms for learning emotional words as emotionally neutral words.

Previous studies have observed significantly slower reaction time in the first presentation to the negative words, relative to the positive and neutral words (Fenske and Eastwood 2003; Kuchinke et al. 2005), interpreted as an interference effect where the negative materials induced a constriction of the focus of attention (Fenske and Eastwood 2003; Smith et al. 2006). Although a similar trend was found in the present study, the initial reaction time differences across the different valence conditions did not reach statistical significance. This discrepancy may be due to task differences. Compared to the emotional category judgment task or the lexical decision task used in previous studies, our perceptual judgment task involved relatively shallow processing. Therefore, the emotional words may not have been semantically processed deeply enough in the first presentation for their emotional valence to have significant effects. Apparently, the attentional constriction induced by the negative materials was transient and no longer present when the same negative stimulus was presented for the second time, resulting in their larger reaction time reduction from the first to the second presentations. This result has also been observed in Thomas and Labar (2005) showing greater repetition priming effect for taboo words than neutral words.

Other than these initial differences, the emotional conditions were not different from the neutral ones in either the final reaction time or the total priming effect, suggesting that after massive repetition practice, the same asymptotic performance level was reached in all conditions regardless of the emotional valence of the stimuli. Similar final convergence has also been observed in previous studies. For example, Salasoo et al. (1985) showed that though words were identified more accurately than pseudowords in the first few presentations, both were identified equally well after five repetitions. Grant and Logan (1993) reported similar lexical decision performance in reaction time for words and non-word stimuli as the number of presentations increased up to 16.

Albeit the above similarities across the three valence conditions, the most interesting findings came from the results regarding the plateau and the saturation periods which were affected by material valence. The plateau periods began slightly earlier for the negative and positive conditions (both at the 4th presentation) than the neutral condition (at the 5th presentation). For the positive words, there was only one short plateau period lasting two time segments, while for the neutral and negative words, there were two plateau periods lasting 2–5 time segments. For the positive words, saturation period was also reached earlier at the 8th presentation than the neutral and negative conditions, both at the 13th presentation. Such results indicate that performance improvement of the positive words was the fastest and most efficient among the three types of words. This conclusion is contingent upon the assumption that the final level of performance obtained with 15 repetitions reflects the true asymptotes for the three conditions. The assumption seems reasonable as our decision of using 15 maximum repetitions was based on literature studies (e.g. Grant and Logan 1993; Lewis and Ellis 2000; Salasoo et al. 1985).

One account for the benefits of positive stimulus valence in language learning is that positively valenced stimuli generally and automatically facilitate word recognition, a view in accordance with a number of theories about emotion and memory (e.g., Bower 1981; Isen 1985, 1987). For instance, it is proposed that emotional states can be represented as nodes in a semantic network and positive materials are better elaborated and interconnected in the cognitive-emotional system than negative material (Ashby et al. 1999; Bower 1981; Isen 1985) so that broad positive schemata are more readily cued to increase the network activation for more efficient processing. In support of such proposals, there have been reports of enhanced elaborative processing of pleasant than of neutral or unpleasant words, as indexed by larger late positive components in event-related potential (ERP) studies (e.g. Herbert et al. 2006).

Alternatively, the benefits of positive stimulus valence in language learning can be understood with the activation versus elaboration model (Graf and Mandler 1984) which proposes that positive representations are more integrated and hence easier to perceive than negative or neutral ones (see similar argument in Kuchinke et al. 2005). Such models would predict and explain benefits not only for positive stimuli but also for external positive affects, such as in leading to greater cognitive flexibility, in facilitating creative problem solving (Ashby et al. 1999), and in promoting careful, thorough, open-minded, and systematic processing (e.g. Estrada et al. 1997; Isen 1999). Specific to the present study, the model would expect that positive words enjoy an advantage in processing efficiency, relative to neutral and negative words.

The present study found that, although there was no effect of emotional valence on the final effects, the time course of language learning, as indexed by improvement period, plateau period and saturation period, was indeed modulated by emotional valence. One practical implication from the present findings is that if one uses repetition strategy in language learning, materials with positive valence can be repeated fewer times but negative and neutral materials need more repetitions as for them performance may continue to improve after a few plateau periods.

Conclusion

The present study used the massive repetition priming paradigm to investigate the role of emotion in implicit language learning. When judging the spatial configuration of individual characters in a list of Chinese words, participants showed comparable total effects of learning, i.e. the same asymptotic level of performance was reached after sufficient massive repetition practice, regardless of the emotional valence of the learning materials. However, the material valence did have significant effects on the time course of learning so that learning of the positive words was faster and more efficient in that it was associated with fewer plateaus of shorter durations and reached saturation earlier, compared with the neutral and negative words. The present study indicates the importance to explicitly consider the role of emotional factors in implicit language learning research. To further understand the role of emotion in language learning, future studies can be conducted to investigate whether the emotional valence of the learning environment also affects learning efficiency in massive repetition priming.

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