Title

ABA, ABC, and AAB renewal in fear conditioning using social stimuli and its quantitative description

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Abstract

A relapse in clinical anxiety following exposure therapy for social anxiety disorder is prevalent and causes serious problems. According to the fear conditioning theory of social anxiety disorder, a part of this relapse can be caused by the renewal effect. This study aimed to investigate whether three renewal effects occur in a fear conditioning procedure that uses social stimuli as both unconditioned and conditioned stimuli, which is an analog preparation of acquisition of social anxiety and reduction by exposure therapy. Sixty-four participants were randomly allocated to four groups (AAA, ABA, ABC, and AAB). They received 9 pairings with a natural face and a negative comment during the acquisition phase and then received 18 pairings with the same face and a neutral comment from the person in the extinction phase. Following extinction, the testing phase was conducted. Context, defined as background colors, used in each phase was different between groups. We conducted two analyses, the ANOVA and Bayesian modeling, to investigate whether three types of renewal effects occur, whether the individual data can be described by an associative model and whether individual differences in learning are related to social anxiety. The ANOVA showed the occurrence of three renewals in the procedure, although the size of their effects was the same. The Bayesian modeling indicated that individual data were generally consistent with the model, and there were some relationships among the estimated parameters and between their parameters and social anxiety. These findings suggest that the relapse following exposure therapy is related to renewal effects,

the effect of each exposure session can be represented by mathematical associative models, and some features of learning in the procedure are related to other features and social anxiety.

Keywords

fear conditioning, social anxiety, renewal effect, associative learning.

Introduction

Social anxiety disorder (SAD) is characterized by a marked fear or anxiety of the social environment, which can be scrutinized by others (APA, 2013). SAD has a high prevalence rate, with a twelve-month prevalence of 6.8% (Kessler et al., 2005), and is associated with serious problems, such as low wages and poor achievement in school (Katzelnick et al., 2001). Exposure techniques have often been used as psychological interventions for SAD (e.g., Hofmann & Otto, 2008), and meta-analysis indicates that exposure-related interventions alleviate their symptoms better than wait-list groups (Mayo-Wilson et al., 2014). However, it is also known that relapse of clinical anxiety often occurs following exposure therapy, referring to the return of fear (Rachman, 1989).

Clinical researchers and therapists have interpreted the relapse from the perspective of fear conditioning (Craske et al., 2008). According to the fear conditioning theory of social anxiety (Lissek et al., 2008), social anxiety is formed by the pairing of traumatic events related to aversive social communications (unconditioned stimulus; US) with neutral social stimuli (conditioned stimulus: CS). Exposure therapy is an application of the extinction procedure following fear conditioning (Craske et al., 2008), which typically reduces the conditioned response (CR) by the presentation of CS without the US following fear conditioning. However, this reduced response can be recovered by various manipulations, such as contextual change (renewal effect; Bouton & Bolles, 1979), suggesting that a part of relapse after an exposure

intervention is caused by the renewal effect because the ordinary exposure interventions often lead to a contextual change between the sessions and the real-life settings. Consistent with this hypothesis, it has been reported that only contextual change following the intervention increases the fear reduced by the exposure session (e.g., Rodriguez et al. 1999; Mineka et al., 1999).

Bouton and Nelson (1998) indicated that the renewal effect could be categorized into three types: ABA, ABC, and AAB renewal. ABA renewal refers to the recovery of a CR caused by conducting acquisition in a context (context A), extinction in a different context from context A (context B), and testing in context A (e.g., Bouton & Bolles, 1979). In this procedure, testing in a novel context (context C) also produces a return of CR, which is ABC renewal (e.g., Bouton & Bolles, 1979). AAB renewal is defined as the reappearance of a CR in a novel context after acquisition and extinction in the same context (e.g., Bouton & Ricker, 1994). Although these effects have been observed in various preparations with rodents (e.g., Bouton & Bolles, 1979) and humans (e.g., García-Gutiérrez & Rosas, 2003), these experiments have mainly used conventional and arbitrarily selected US (e.g., loud noise, electrical shock, or aversive picture) and CS (e.g., tone or geometric shape). It is difficult to directly apply these findings to clinical assessments or interventions because learning is strongly affected by the relationship between stimuli and responses used in the experiment, widely known as preparedness (Seligman, 1970). Thus, there is a large gap between their experimental environments and clinical settings. To

resolve this issue, Carpenter et al. (2019) recommended using fear-relevant stimuli as CS and aversive stimuli that are conceptually related to CS as US in an experiment of fear conditioning for clinical application. Therefore, investigating the renewal effect in fear conditioning using social stimuli as US and CS can provide important findings to understand and decrease relapse following exposure therapy for SAD.

Findings of fear conditioning using social stimuli as both CS and US are accumulated to investigate various clinical purposes, such as differences in the degree of CR between healthy participants and individuals with SAD (e.g., Tinoco-González et al., 2015). As a finding of recovery of CR after extinction, Nihei et al. (2021) showed that the ABA renewal effect occurs in this preparation. Although this finding suggests a relationship between the renewal and relapse of social anxiety, a relapse following exposure sessions might not be caused by ABA renewal only. When a patient encounters an extinguished CS in a new situation following the intervention and shows a relapse, the relapse is likely the ABC or AAB renewal. Therefore, in this study, we examine not only ABA renewal, but also ABC and AAB renewal.

This study investigated three types of renewal effects (ABA, ABC, and AAB) from multiple analyses using ANOVA and Bayesian modeling. In ANOVA, whether three types of renewal effects occurred was examined using the framework of the significance test and Bayes factor. We used Bayesian modeling to examine whether the real data support the numerical simulation of an associative model. Recently, we developed a new mathematical model to

explain the recovery-from-extinction effects, including all renewal effects (Nihei et al., 2020).

The model is represented by the following formulae:

$$CR = Ve * S^e + Vi * S^i \quad (1)$$

$$\Delta Ve_t = \alpha^e (\lambda - \Sigma(Ve_{t-1} * S^e) + \Sigma(Vi_{t-1} * S^i)) \quad (2)$$

$$\Delta Vi_t = \alpha^i (0 - \Sigma(Ve_{t-1} * S^e) + \Sigma(Vi_{t-1} * S^i)) \quad (3)$$

where Ve and Vi represent the excitatory and inhibitory associations between the target CS and US, respectively. Thus, CS-US pairings increase the Ve according to Equation 2, and the presentation of the CS alone decreases Vi according to Equation 3. S indicates a similarity between two contexts and determines retrieval strengths of both associations, which is described as S^e for the similarity between acquisition and one context and as S^i for the similarity between extinction and one context. CR is determined by the sum of both associations retrieved in the phase (Equation 1). Both α s are rate parameters in the Ve (α^e) and Vi (α^i), and λ is an asymptote parameter. The model assumes that each similarity affects the retrieval of their associations in the phase, changing the degree of expressed CR and the magnitude of learning determined by a prediction-error rule (e.g., Rescorla & Wagner, 1972). Moreover, we also conducted an exploratory correlation analysis to examine whether there is a relationship between the characteristics of learning in this procedure and other characteristics or social anxiety.

Material and methods

Participants

Sixty-four graduate and undergraduate psychology students (46 female) with a mean age of 20.38 years ($SD = 2.26$, range: 18-27) participated in this experiment. The sample size was determined by a prior power analysis ($f = 0.25$, $\alpha = 0.95$, $\beta = 0.80$, correlation among repeated measures = 0.38) based on our previous study (Nihei et al., 2021) using G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009). Although the result indicated to be necessary for 60 participants to detect the effect, the number of participants was determined to be 64 to equalize the type of stimuli used in each group by counterbalance. They were randomly allocated to one of the four groups (AAA, ABA, ABC, and AAB; $n = 16$ in each group). Two participants (one of Group AAA and Group AAB) were excluded from all analyses because of technical errors during the experiment, and new participants' data replaced their data.

Apparatus and Stimuli

All stimuli were the same as those used by Nihei et al. (2021). The neutral faces of two actors (male and female) served as CS + or CS- and three movies of a negative comment ("Go away!" "Do you know what's wrong?" and "I hate you!" in Japanese), and the face of the actors served as the US. We also used three movies of a neutral comment ("I can't eat anymore," "I wonder what I should do," and "I am hungry" in Japanese) and the face of the actors as neutral stimuli (NS). Background colors (red, blue, and white) were used as contextual stimuli.

The size of the CS, US, and NS on display was 14.3 cm × 23.7 cm. The volumes of the US and NS were less than 80 dB (62.9–78.9 dB), and these stimuli were delivered via headphones (Bose Inc., QuietComfort 35 wireless headphones). The experiment was run on a Dell desktop computer (XPS 8910) with a 19.5-inch computer monitor (Dell Inc., E2014HF), programmed with PsychoPy2 (version 1.85.3; Peirce, 2007).

Measures

US expectancy. US expectancy was measured using a 9-point Likert scale ranging from 0 (certainly no aversive comments) to 9 (certainly aversive comments), which was used to assess the CRs following each presentation of the CSs in all phases. Participants were asked to rate the extent to which they expected the CS would be followed by the US with mouse-clicking.

The Short Fear of Negative Evaluation scale (SFNE). The SFNE (Leary, 1983; the Japanese version was developed by Sasagawa et al., 2004) was used to assess social anxiety. This scale consists of 12 items on a 5-point Likert scale, ranging from 1 (not at all characteristic of me) to 5 (extremely characteristic of me). Some examinations investigating psychometric properties of the scale (e.g., Rodebaugh et al., 2004; Nihei et al., 2018) have indicated that the scale contains a two-factor structure (eight straightforward items and four reversed items), and only the straightforward items are related to social anxiety. Therefore, we used only eight straightforward items in the SFNE.

Procedure

All participants gave informed consent and were then asked to complete the SFNE before starting the experiment. Next, the participants were told that pictures of individuals' faces and movies with them talking would be presented during the experiment and were instructed on how to rate the US expectancy scale by an experimenter. Information about the relationship between CS and US was not provided to the participants.

This experiment consisted of three phases: the acquisition, extinction, and test. The experimental design is presented in Table 1. First, in the acquisition phase, each CS was presented nine times. CS+ was always paired with the US, and CS- was consistently followed by NS. All groups experienced these trials in Context A. Next, both CSs (CS+ and CS-) were paired with NS during the extinction phase. Groups AAA and AAB participants received these trials in Context A, while Groups ABA and ABC received the trials in a different context from the acquisition phase (Context B). Finally, during the test phase, both CSs were paired with the NS, as in the extinction phase. In this phase, Groups AAA and ABA were tested in Context A, while Group AAB in Context B and Group ABC in a new context (Context C).

Table1. Design table in the study

Group	Acquisition: 9 trials	Extinction: 18 trials	Test: 3 trials
AAA		A: CS+ $\rightarrow$ NS A: CS - $\rightarrow$ NS	A: CS+ $\rightarrow$ NS A: CS - $\rightarrow$ NS
AAB	A: CS+ $\rightarrow$ US	A: CS+ $\rightarrow$ NS A: CS - $\rightarrow$ NS	B: CS+ $\rightarrow$ NS B: CS - $\rightarrow$ NS
ABA	A: CS - $\rightarrow$ NS	B: CS+ $\rightarrow$ NS B: CS - $\rightarrow$ NS	A: CS+ $\rightarrow$ NS A: CS - $\rightarrow$ NS
ABC		B: CS+ $\rightarrow$ NS B: CS - $\rightarrow$ NS	C: CS+ $\rightarrow$ NS C: CS - $\rightarrow$ NS

Note: CS+ and CS- indicate the CS used in this study. The US and NS represent a type of stimulus followed by each CS. A, B, and C represent the contexts used in the phase.

In all trials, the CS was presented for 7s, and then the US expectancy scale appeared. When the participant rated the expectancy scale, the CS and the scale disappeared, and then the US or NS was presented. The order of presentation of CS+ and CS- was semi-random with the restriction that CS+ or CS- could not be presented twice consecutively. The order of presentation of the three USs and NSs was also semi-random, with the constraint that the same stimulus could not be presented more than twice in succession. The inter-trial interval was randomly determined between 5-8 s. The type of CS and the color of contexts were counterbalanced across participants. This study was approved by the Senshu University Human Research Ethics Committee (19-DL167001-2).

Analyses

We conducted two analyses to achieve the aim of this study. All analyses were conducted using R software (R Core Team, 2016, version 3.4.2). First, mixed ANOVAs were conducted on US expectancy scores to test whether three renewal effects occurred. Although we determined the sample size according to the criteria described in the “Participants” of the “Methods” section, we noticed that it was a mistake after the analyses were completed. The actual sample size necessary to detect the effect observed in a previous study (Nihei et al., 2021) is $n = 284$ ($f = 0.11$, and other parameters are the same for the initial setting). Therefore, we additionally conducted a Bayesian ANOVA using JASP (version 0.14.1.0; JASP Team, 2020), which was unplanned before the analysis because the Bayesian ANOVA is less susceptible to lack of power than the traditional ANOVA using significance tests. Both ANOVAs had between-subjects factor group (AAA, ABA, ABC, and AAB) and CS (CS+, CS-) and the within-subject factor trial (acquisition phase: 9 trials; extinction phase: 18 trials; test phase: 3 trials). In traditional ANOVA using F statistic, Greenhouse-Geiser correction was applied when the sphericity was violated, and the significance level was set at 0.05. In the Bayesian ANOVA, each main and interaction effect was evaluated using the Bayes factor (BF), which refers to the proportion of marginal likelihoods of the two models, indicating the degree of relative evidence between both models (Lee & Wagenmakers, 2013). For example, $BF_{10} = 2$ indicates that it is twice as likely to observe data in model 1 as compared to model 0. In the current analysis using BF, the ANOVA model including a factor to be analyzed was model 1,

and a model without the factor was model 0, which was used to examine the effect of main and interaction effects in the traditional ANOVA. The interpretation of the BF was based on Jeffreys' criteria (Jeffreys, 1961).

Second, the Bayesian modeling was conducted to achieve two aims: whether observed data can be described by the model of Nihei et al. (2020) and whether individual differences in the estimated parameters are related to other parameters and social anxiety. For the first aim, the discrepancy between the observed data and the model was assessed by qualitative posterior predictive checking (PPC), which evaluates whether posterior predictive values from estimated parameter values resemble the actual data by visual inspection (Kruschke, 2013). The analyses would show whether the real data support the numerical simulation of the associative model. For the second aim, we conducted an exploratory analysis to investigate whether the characteristics of learning assumed by Nihei et al.'s model (i.e., each rate in acquisition and extinction (α^{Ve} and α^{Vi}), the intensity of US (λ), and similarities between contexts (S^e and S^i) are related to social anxiety.

In Bayesian modeling, ensuring proper prior distributions and methods for parameter estimation is important to obtain valuable findings. As the prior of each parameter, the weakly informative prior distribution was used as follows:

$$\alpha^{Ve} \ \& \ \alpha^{Vi} \sim Beta(1,1) \tag{4}$$

$$\lambda \sim Normal(\mu_{\lambda}, \sigma_{\lambda}), \quad \lambda > 0 \tag{5}$$

$$\mu_{\lambda} \sim \text{Normal}(0, 100), \quad \mu_{\lambda} > 0 \quad (6)$$

$$\sigma_{\lambda} \sim \text{Normal}(0, 1), \quad \sigma_{\lambda} > 0 \quad (7)$$

$$S^e \ \& \ S^i \sim \text{Beta}(1, 1) \quad (8)$$

In the Bayesian estimation, the posterior distribution was approximated by the Markov Chain Monte Carlo method using Stan (Stan Development Team (2018): version 2.17) and R (version 3.4.2). Based on 20,000 iterations and 5,000 warmups, post-random values were generated by four independent chains. We decided to achieve model convergence when the $\hat{R}$ value of each parameter was less than 1.10.

Results

ANOVA

Figures 1 and 2 show the means of the US expectancy for each CS in the experiment. In the acquisition phase, group $\times$ CS $\times$ trial ANOVA revealed a significant CS $\times$ trial interaction ($F = 169.11, p < .001, \text{BF}_{10} = 9.807 * 10^{13}$), and no group $\times$ CS $\times$ trial interaction was significant ($F = 1.75, p = 0.38, \text{BF}_{10} = 3.193 * 10^{-6}$). The post-hoc analysis indicated significant differences between each CR on the initial trial and last trial ($p < .001, \text{BF}_{10} < 7.196 * 10^{18}$) and between the CRs to both CSs in the last trial ($p < .001, \text{BF}_{10} = 2.889 * 10^{39}$), suggesting that the CS+ increased and the CS- decreased over trials. These results showed that successful differentiation was achieved in all the groups during the acquisition phase.

Figure 1. Means of the US expectancy ratings to the CS+ in all groups. The error bars indicate standard errors.

Figure 2. Means of the US expectancy ratings to the CS- in all groups. The error bars indicate standard errors.

For the extinction phase, the ANOVA yielded a significant interaction effect between CS and trial ($F(17, 1020) = 54.14, p < .001, BF_{10} > 9.906 \times 10^{13}$). The post-hoc analysis reported a significant difference between the initial trial and last trial in CS+ ($p < .001, BF_{10} = 5.783 \times 10^{25}$). There was a mixed result in the difference between the CRs to both CSs in the last trial ($p = .10, BF_{10} = 23862.00$), which showed that the CR to the CS+ decreased over trials, but possibly did not decrease to the same level as CS-. Although the result of group $\times$ trial interaction ($F(51, 1020) = 2.54, p < .001, BF_{10} = 0.38$) was also mixed, the post-hoc analysis

showed that this effect was not observed in the last trial ($p < 0.16$). Based on these results, we concluded that extinction was achieved in all the groups.

For the test phase, the ANOVA revealed no significant differences in group $\times$ CS $\times$ trial ($F(6, 120) = 1.86, p = .09, BF_{10} = 0.09$) and group $\times$ CS interaction ($F(3, 60) = 1.81, p = .15, BF_{10} = 71.91$) are inconsistent by analyses, showing that no renewal effects could occur in the test phase. A significant main effect of the group was found, and the post-hoc analysis indicated that the CR of Group AAA was lower than that of the other three groups ($p < .01, BF_{10} = 30361.68$). These results indicated that an increment occurs not only in the CS+ but also in the CS- during the test phase in the three renewal groups.

Because the result of the test phase was unexpected, we additionally performed an exploratory ANOVA to investigate the change of the CR between the last trial in the extinction phase and the initial trial in the test phase to determine group differences in the CR to each CS. In the ANOVA, group $\times$ CS $\times$ trial interaction ($F(3, 60) = 6.18, p = .001, BF_{10} = 3.72$) was significant. The post-hoc analysis indicated that there was no group difference in the CRs to the CS+ on the last trial in the extinction phase ($F(3, 60) = 2.42, p = .075, BF_{10} = 0.93$). A significant difference between the group on the initial trial in the test phase was confirmed in the CS+, which indicates Group AAA was lower than other groups ($p < .01, BF_{10} = 41.63 - 920.38$) in the CS+. There was no difference between the ABA, ABC, and AAB groups ($p > .24, BF_{10} < 1$). This result showed that recovery of the CR to the CS+ is significantly greater

than that of CS- in the initial trial in the testing phase, indicating the possibility that the renewal effect occurred and that the three types of renewal caused the same degree of recovery of the CR.

Bayesian modeling

Figure 3 shows the results of PPC in two representative participants from each group. The black line indicates the observed data (only the CR to the CS+), and the gray area represents the 95% credible interval with posterior predictive values. The left panel shows that the intervals cover the actual data, and similar patterns were confirmed in many participants in all groups (see Appendix A). However, in some participants (right panel), there was a slight discrepancy between the data and the interval. These results indicate that many of the individual data on acquisition, extinction, and renewal effects of fear conditioning using social stimuli can be generally represented by Nihei et al.'s model although some data were inconsistent with the model.

Figure 3. Representative individual data in the experiment and 95% credible interval with posterior predictive values in the Bayesian modeling. The left panel shows generally consistent data with the distributions, and the right panel shows inconsistent data. (The line is a measured value. Dark black represents a 50 % credible interval, and light black represents a 95 % credible interval).

Next, we examined the correlations among the parameters and between the parameters and the SFNE. These correlations are shown in Table 2. Medium correlations ($|r| > .30$) between the parameters were confirmed in some pairs: α^e (learning rate during acquisition) and α^i (learning rate during extinction), α^i and λ (asymptotic value on the CR), and S^e

(similarity between acquisition and a novel context in excitatory association), and S^i (similarity between acquisition and a novel context in inhibitory association). In the relationships between their parameter values and the SFNE, small correlations ($|r| = .10 - .30$) were confirmed in some pairs, which were both α_s and λ in all participants and α^{Vi} and S^e in the participants of all renewal groups. The results suggest some moderate relationships between some variables in the model, and these variables are slightly related to the degree of social anxiety.

Table 2. The mean, standard deviation, and their correlations of SFNE and estimated parameters.

		All groups ($n = 64$)					
		M	SD	1	2	3	4
1	α^e	0.50	0.24	-			
2	α^i	0.17	0.15	0.40	-		
3	λ	9.05	0.12	0.22	0.35	-	
4	$SFNE$	28.52	6.62	0.11	-0.15	0.10	-

		Renewal groups only (ABA, AAB, ABC; $n = 46$)							
		M	SD	1	2	3	4	5	6
1	α^e	0.53	0.23	-					
2	α^i	0.17	0.16	0.38	-				
3	λ	9.04	0.12	0.26	0.33	-			
4	S^e	0.91	0.08	0.15	-0.006	0.35	-		
5	S^i	0.58	0.30	0.001	0.03	0.01	0.34	-	
6	$SFNE$	28.38	6.28	0.09	-0.28	0.06	0.15	-0.02	-

Note: α^e and α^i represent rate parameters in excitatory and inhibitory learning, respectively. λ represents the intensity of the US. S^e and S^i represent the similarity between contexts in testing and acquisition and extinction, respectively. SFNE is a score of the Short Fear of Negative Evaluation scale.

Discussion

This study aimed to confirm whether three renewal effects (ABA, ABC, and AAB) occur in fear conditioning using social stimuli as both US and CS. The analysis investigating the degree of relapse (i.e., the difference in the CR between the last trial of extinction and the

first trial of the test phase) demonstrated all types of renewal, although there was no difference in the magnitude of the renewals. In addition, we conducted the Bayesian modeling to examine whether Nihei et al.'s model can describe the data and whether parameter values estimated for each participant (i.e., individual differences in psychological variables in the model) are related to other parameters or social anxiety. The results showed that the individual data could be mathematically represented in the model, and some characteristics of learning in the participants were related to other characteristics and social anxiety.

These results are consistent with a previous study that investigated ABA renewal using the same stimuli (Nihei et al., 2021) and suggest that all renewal effects occur after exposure therapy for social anxiety. Based on this finding, procedures that reduce renewal effects, such as exposure in multiple contexts (e.g., Olatunji et al., 2017) or the use of retrieval cues (e.g., Shin & Newman, 2017), should be effective for this relapse. Contrary to some studies (e.g., Thomas et al., 2003), the current study did not identify a difference between their renewals. This result might indicate that the fear of social stimuli or highly prepared conditioning is very sensitive to a context change following extinction. Thus, a context change after the extinction procedure can strongly affect extinguished fear, regardless of the context stimuli used in each phase. However, the results should be carefully interpreted because this analysis was additional, and planned analysis showed that the effect of the test phase was insignificant.

The current finding that the data are consistent with mathematical representations of

the model suggests that the effects of exposure therapy, which is an application of extinction, and relapse of social anxiety following the sessions, might be mathematically represented by the model. Thus, it is possible to mathematically represent the change in symptoms by each exposure session if the parameter values for each patient can be estimated. It is difficult to mathematically predict the change in symptoms using the traditional model of exposure therapy (e.g., Foa & Kozak, 1986) because many of their models are not formal or mathematical models. Recently, computational psychiatry attempted to represent the effect of exposure therapy on each session mathematically, showing that an exponential function is an appropriate model to represent the reduction in fear within a session (Portêlo et al., 2021). Based on the numerous findings indicating that the exposure therapy is an analog of the extinction procedure (e.g., Craske et al., 2008) and the current findings, it is possible that associative models also provide a good mathematical description of the change in fear by exposure sessions.

Another aim of the Bayesian modeling was to examine relationships among learning characteristics in this fear conditioning procedure and the relationships between their characteristics and social anxiety. It was confirmed that medium correlations exist between the learning rates during acquisition and extinction and between the rate during extinction and the asymptote of the CR determined by US intensity, suggesting that participants who acquired fear rapidly or strongly tended to decrease the CR during extinction rapidly. S^e was related to both λ and S^i , indicating that the participants who generalize excitatory learning to other

contexts tend to generalize inhibitory learning well and develop strong fear during acquisition. The analysis also showed small relationships between SFNE and some parameters, showing that the participants with high social anxiety tended to show enhanced and rapid acquisition, delayed extinction, and excessive generalization of excitatory learning to a novel context.

The results of the current correlational analysis provide some implications for the characteristics of learning in Pavlovian conditioning. Annau and Kamin (1961) showed that a more intense US produces rapid acquisition and delayed extinction. Since the value of λ reflects the strengths of the US perceived by the participants, there is expected to be a positive correlation between λ and the rate during acquisition and a negative correlation between λ and the rate during extinction. This expectation was supported only for the rate during the acquisition. The result of the correlation with S^e suggests that two similarities include some common elements. In Nihei et al. 's model, based on findings of the stimulus generalization (e.g., Dunsmoor et al., 2011), the similarities can be categorized into physical similarity defined by the distance of physical dimensions, such as size or wavelength, and conceptual similarities defined by psychological factors, such as a rule or inductive reasoning (e.g., Lee et al., 2019). The result that two Ss is positively related can reflect some common factors of conceptual similarity between S^e and S^i because the physical features of contexts in the procedure were counterbalanced. Thus, conceptual similarity, such as rules or inferences about the relationship between CS, US, and the context formed by the participant, may affect both similarities.

The results of the SFNE are difficult to interpret. While the current results are consistent with many findings that healthy participants with high anxiety and patients with anxiety disorder exhibit impaired extinction and excessive generalization to novel stimuli (e.g., Duits et al., 2015; Wong & Lovibond, 2018), the results are inconsistent with previous studies that showed that the degree of anxiety is not related to enhanced acquisition (e.g., Duits et al., 2015). This result was also identified in a procedure similar to the present study (Fung & Alden, 2020). This discrepancy might be due to the different types of values used in the analysis. Unlike the analyses of other studies that investigated the relationship between observed CR and anxiety, the present study used estimated parameter values to represent some characteristics of learning based on Nihei et al.'s model. An advantage of this analysis is that the observed data can be mathematically partitioned into some components, such as the learning speed or asymptote of the CR. Thus, the current analysis might be able to show the relationships between each component and anxiety. However, it should also be noted that the effect sizes of the results in this analysis are generally small, and this analysis is exploratory. Therefore, to examine the cause of this discrepancy, future studies with a planned sample size to detect this effect should be conducted.

In summary, this study investigated whether three types of renewal effects, ABA, ABC, and AAB renewal, occur in fear conditioning using social stimuli as US and CS. The results demonstrated that recovery of the CR was observed in the testing phase, and there was no

difference between their renewals, although the analysis was unplanned and the main analysis investigating the difference in the CR between all groups in the testing phase was nonsignificant. In addition, the Bayesian analysis showed that Nihei et al.'s model fits the data, and some features of learning in the participants are related to other features and social anxiety.

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Appendix A

Fig. A.1 All participant's data and 95% credible interval with posterior predictive values in the Bayesian modeling. (The line is a measured value. Dark black represents a 50 % credible interval, and light black represents a 95 % credible interval).

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