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Effects of emotion and sex difference on item-method directed forgetting

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ABSTRACT

It is crucial to remember or forget others' faces in daily life. People can intentionally forget things they wish to forget, a phenomenon called directed forgetting (DF). This study examined the effects of stimuli's emotions and sex differences in participants and stimuli on DF. We used happy and angry faces as the items in a typical item-method paradigm and conducted three behavioral experiments. In Experiment 1, we recruited 60 participants to examine how emotions of stimuli and sex differences in participants and stimuli affected DF. In Experiment 2, we recruited 60 female participants and manipulated the durations of items presented during the study phase to examine whether the selective rehearsal theory was held. In Experiment 3, we recruited 50 female participants and attached recognition cues to the items presented during the test phase to examine whether the inhibitory control theory was held. We treated the sex of participants in Experiment 1, the durations of items presented during the study phase in Experiment 2 as the between-subject factors, and emotion and sex of stimuli as the with-subject factors. We conducted the mixed-design ANOVA for corrected hit rate, sensitivity, and bias based on the signal detection theory. As a result, we found that DF occurred easily for male participants, whereas not for female participants because of females' superior memorial performances and stronger sensitivities. Furthermore, we found that female participants owned the best and worst recognition rates for angry female faces and happy male faces, respectively. Our results supported the selective rehearsal theory, suggesting manipulations during the study phase had the potential to help females forget what they wished to forget. We presumed that psychologists and therapists should pay attention to the roles of sex difference in twofold, self and others, when studying people's memory and forgetting. Furthermore, the sensitivity of self and the emotion of others should be considered as well.

1. Introduction

Please imagine a scenario: "You are walking in the street. A person walking towards you gives you a big smile and waves his hand to greet you. You feel very awkward because you do not remember him at all." This scenario is very common as long as you live in a social

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world. You can meet hundreds of people every day, but you want to remember the faces of important people and forget the faces of people who give you bad experiences. By understanding the factors that can affect your memory and forgetting, you may control your memory deliberately to remember or forget the faces you have met. In this study, we aimed to examine how others' emotions and sex differences affected your memory. We hoped that our results could help people control their memories and provide insights for psychologists and therapists into how to help patients forget miserable experiences.

Researchers usually use the directed forgetting (DF) paradigm to examine how peoples remember or forget things. DF depicts that participants can remember the information they are told to remember more efficiently than the information they are told to forget [1]. As a result, people can intentionally forget irrelevant and outdated things to facilitate the relevant cognitive function [2]. The item-method paradigm is one of the common paradigms used to study DF [1,3,4]. It includes two phases: during the study phase, an item is presented to participants at a time, followed by instruction of "remember" or "forget"; during the test phase, participants are asked to respond whether the item has been presented during the study phase or not. The items can be words, pictures, or sounds [5–10]. DF is symbolized by the higher recognition rate of items followed by "remember" instruction than those followed by "forget" instruction. Researchers have proposed two theories to explain the underlying mechanism of DF: selective rehearsal theory and inhibitory control theory [11–13]. Selective rehearsal theory argues that participants can keep the items in working memory through rehearsal and further elaborately encode the items followed by "remember" instruction. In contrast, inhibitory control theory argues that participants can elaborately encode the items irrespective of the following instructions but stop the retrieval of items followed by "forget" instruction.

Previous studies have reported how emotions affected DF, whereas different conclusions were drawn [5–7,14–17]. For example, Hauswald et al. found that DF occurred for neutral pictures but not for negative pictures [6]; Bailey & Chapman reported an attenuated DF for positive and negative words than neutral words [5]; Otani et al. found that DF occurred for positive and neutral pictures but not for negative pictures [17]; Marchewka et al. found that DF occurred equally for disgustful, fearful, sad, and neutral pictures [15]; Quinlan & Taylor found that DF occurred for happy, angry, and neutral faces [7]. From our point of view, there might be several possibilities to explain the different conclusions of the effect of emotion drawn from previous studies [5–7,14–17]. First, the types of items were different from study to study. It has been shown that the cognitive processing mechanisms of DF between pictures and words might be different [18]. Also, emotional faces with specific facial features and social values (e.g., angry faces signify potential threats) might own different affective characteristics from emotional words or pictures [7,8]. Second, the emotions of items were defined differently. For example, Hauswald et al. assessed the valence and arousal scores for neutral and negative pictures without considering the concrete emotions, whereas Marchewka et al. classified the pictures into three concrete emotions [6,15]. Third, the durations of items presented during the study phase varied from 0.5 s to 5 s [5–8]. Although Quinlan & Taylor found comparable DF effects for a duration of 0.5 s and 1 s, they acknowledged the different processing times for different emotions, especially for the difference between angry and happy emotions [7].

Another concern that should be mentioned is sex differences [8,10]. The sex differences are twofold, including differences in participants and facial stimuli. Lovén et al. reported a female's own-gender bias in face recognition memory, suggesting that female participants could remember more female faces than male faces, whereas male participants could not [19,20]. Montagne et al. found that female participants owned higher accuracies and stronger sensitivities in labeling facial emotions than male participants [21]. By using auditory stimuli, Yang et al. reported an attenuated DF effect for female prosody than male prosody, and female participants could be less affected by distraction and employ strategies to retain content information [10].

To summarize, we aimed to examine the effects of stimuli's emotions and sex differences in participants and stimuli on DF. Firstly, we hypothesized that stimuli' emotions could affect DF differently, especially when facial pictures were used as stimuli. Human faces contain ample biological and social information, such as identity, race, gender, age, and emotions [22]. Emotions can convey crucial information to the recipient [23]. For example, a smile implies friendliness, support, and encouragement, whereas anger implies discontent and threat. In the current study, we selected happy and angry emotions among the 27 different emotions reported by Cowen & Keltner [24]. There is always a debate on "happy face advantage," indicating happy faces can be better remembered than angry faces, and "angry face advantage," indicating angry faces can attract a narrow attentional focus more quickly than happy faces [25–28]. The well-discussed debate can help us to dig into the effect of emotion on DF. Secondly, we hypothesized that sex differences in participants and stimuli could affect DF differently due to the interaction between emotions and sexes. Previous studies have reported that anger could be linked with males and happiness with females, a so-called social gender role [29,30]. Tay & Yang found that angry male faces and happy female faces were better recognized than vice versa, and female participants had more pronounced DF effects than male participants [8]. Although the social gender role is not robust, with Montagne et al. reporting no such role in their study, we expected to find the interaction between emotions and sexes [21]. Thirdly, we hypothesized that the effects of stimuli's emotions and sex differences in participants and stimuli on DF might be explained by either selective rehearsal theory or inhibitory control theory. Selective rehearsal theory can be examined by varying the durations of items during the study phase; inhibitory control theory can be examined by manipulations during the test phase, wherein recognition cues surrounding the stimuli were provided to hint participants at the instruction of items [31]. Therefore, we manipulated the duration of items during the study phase and the existence of recognition cues during the test phases. If the selective rehearsal theory is held, participants will rehearse the items enough times until they remember the items for the longer duration of items during the study phase, thus having difficulty forgetting the items and leading to attenuated DF [32–35]. The duration of items presented during the study phase would affect participants' performances, with the significant DF phenomenon for a shorter duration than a longer duration. On the other hand, if the inhibitory control theory is held, for the condition accompanying with recognition cue during the test phase, the retrieval of items followed by "forget" instruction would be enhanced, thus improving the corresponding recognition rate and leading to attenuated DF.

We conducted three experiments and used facial stimuli with different emotions (happiness and anger) and sexes (female and male) as the items. In Experiment 1, we recruited female and male participants and adopted the logic from the study of Tay & Yang, wherein emotional faces were presented during the study phase, and neutral faces were presented during the test phase [8]. In the following experiments, we recruited only female participants. We manipulated the durations of items presented during the study phase and the existence of recognition cues attached to the items during the test phase in Experiment 2 and Experiment 3, respectively, to examine which theory (selective rehearsal theory and inhibitory control theory) was proper for explaining female participants' DF phenomenon.

Experiment 1. effects of emotion and sex difference on directed forgetting

1.1. Objective

In this experiment, we aimed to examine how emotions of stimuli and sex differences in participants and stimuli affected directed forgetting (DF). We recruited female and male participants and used happy and angry facial stimuli in an item-method paradigm.

2. Methods

2.1. Participants and apparatus

We conducted the prior power analysis using G*Power version 3.1.9.6 to determine the minimum sample size required to test this experiment [36]. For an effect size of 0.25 and an achievement of 95% power, we needed at least 24 participants to reach a significance criterion of 0.05. Therefore, we recruited 60 undergraduates with an average age of 21.0 years old (standard deviation (SD) was 2.9 years old, including 28 females) through an advertisement posted on the participants' pool of the Shaanxi Normal University. The participants would receive a monetary reward for completing the experiments. The participants had a normal or corrected-to-normal vision. We obtained informed consent from each of them. The Ethics Committee of Shaanxi Normal University approved the protocol (HR 2020-10-008).

The experiment was programmed by E-Prime 2.0 software on a Lenovo computer. E-prime is a psychology software tool wherein researchers can implement experimental procedures through an intuitive graphical user interface. The stimuli were presented on a monitor with a 1280 × 1026 pixels resolution. The background of the monitor was kept white during the whole experiment.

2.2. Stimuli and procedure

The facial stimuli were adopted from the Chinese Facial Affective Picture System (CFAPS) [37]. CFAPS was created by recruiting expressers and rated by raters using a 9-point scale. As a result, CFAPS consists of 870 facial expression pictures and is classified into seven emotion types (anger, disgust, fear, sadness, surprise, happy, and neutral). We chose happy and angry stimuli in the current study.

Prior to the formal experiment, we recruited 40 extra students with an average age of 19.0 years old (SD was 0.8 years old, including 21 females) to rate the valence, arousal, distinctiveness, and attractiveness of the stimuli by using a seven-point scale ranging from 1 (not at all) to 7 (very much so) [8]. The detailed results are summarized in Table 1. The average scores across 40 students were listed with the corresponding standard errors (SE) written in parentheses. As a result, thirty-two emotional stimuli (343 × 396 pixels, eight stimuli for each condition) with comparable scores (all $ps > 0.05$) between female and male stimuli on the four dimensions were selected for the study phase. For the stimuli presented during the test phase, inspired by the study of Tay & Yang, neutral stimuli were used to avoid the possible effects of expressive markers (e.g., lowered eyebrows on angry faces) on facial identification [8,29]. As a result, thirty-two neutral stimuli with the same identity as the 32 emotional stimuli and 32 neutral stimuli with the novel identity were used during the test phase. Please refer to the top and middle panels in Fig. 1A for examples of the stimuli.

Before the formal experiment, we disclosed the objectives of this study to all participants. The participants knew what kinds of stimuli they would see in advance. The experiment was conducted by experimental manipulation. The formal experiment was comprised of three consecutive phases: study phase, interference phase, and test phase. Firstly, as shown in Fig. 1B, the study phase began with a fixation cross presented at the center of the monitor. After 0.5 s, the fixation cross was replaced by a facial stimulus with a duration of 3 s. The facial stimulus was randomly chosen from the 32 emotional stimuli we selected, resulting in 32 trials for each participant. After that, the fixation cross reappeared and lasted for 1 s. Finally, an instruction to direct participants to remember or

Table 1
Mean scores of facial stimuli in each dimension with four combinations (two sexes × two emotions). The corresponding standard error was written in parentheses.

		Dimensions			
		Valence	Arousal	Distinctiveness	Attractiveness
Female stimuli	Happy	4.28 (0.38)	3.19 (0.33)	3.27 (0.29)	3.31 (0.35)
	Angry	1.93 (0.27)	2.78 (0.14)	2.76 (0.28)	2.21 (0.06)
Male stimuli	Happy	4.12 (0.18)	2.99 (0.20)	3.04 (0.19)	3.02 (0.12)
	Angry	1.93 (0.39)	2.90 (0.21)	2.96 (0.25)	2.21 (0.06)

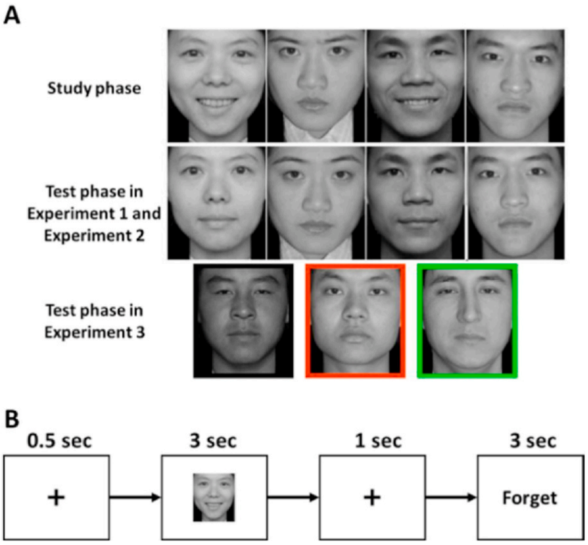


Fig. 1. Stimuli and procedure of the experiments. A) the top panel is the example of the stimuli presented during the study phase; the middle panel is the example of the stimuli presented during the test phase in Experiment 1 and Experiment 2; the bottom panel is the example of the stimuli presented during the test phase in Experiment 3. B) the procedure of the study phase.

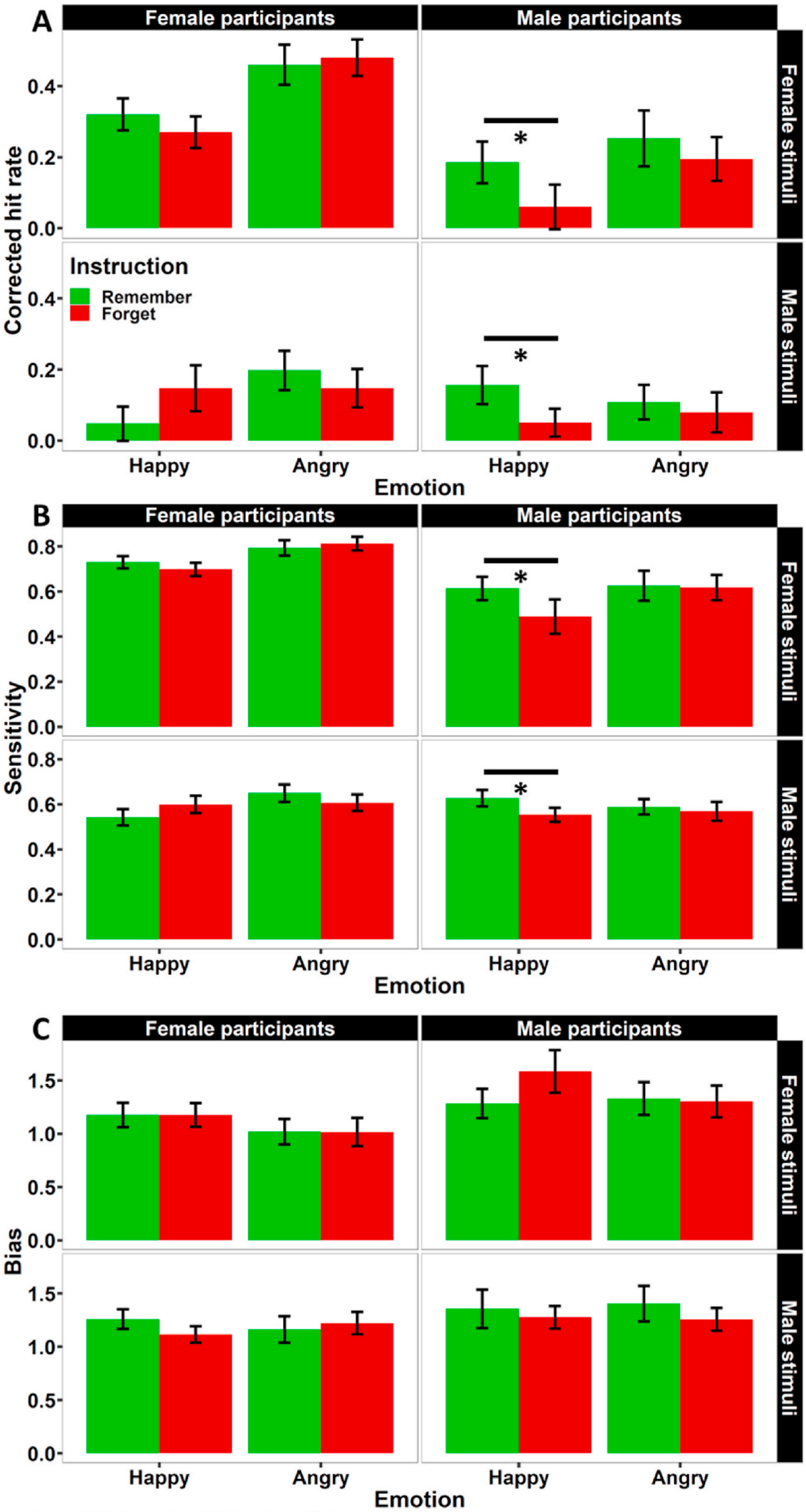
forget the facial stimulus presented in the current trial was presented for 3 s. The two types of instructions were randomly chosen and assigned 16 trials for each. The next trial commenced successively without extra intervals. After the study phase, the interference phase included 20 trials, wherein participants were asked to perform a mathematical addictive task. This phase was added to reduce the recency effects [8,17]. Lastly, during the test phase, thirty-two studied stimuli and 32 unstudied stimuli with neutral emotions were presented, resulting in 64 trials in total. Participants were asked to judge whether the neutral stimulus was presented during the study phase or not by pressing the left or right mouse button, respectively. They should respond as quickly and accurately as possible. Note that the matchup between responses and mouse buttons varied among participants.

2.3. Data analysis

Data were analyzed using R, version 4.1.3 (R Core Team, 2020) and the package ggplot 2, version 3.3.5 [38]. Firstly, we reorganized the raw data based on the signal detection theory: the hit (H) was referred to as the proportion of "yes" response to a stimulus which was indeed presented during the study phase; the false alarm (FA) was referred to as the proportion of "yes" response to a stimulus which was not presented during the study phase; Herein, H was calculated at the individual trial level, including the within-subject factors (emotion of study stimulus, sex of study stimulus, and instruction) and between-subject factors (sex of participant). On the other hand, FA was calculated at the level of within-subject factors (sex of test stimulus) and between-subject factors (sex of participant) due to the absence of the studied stimulus. Secondly, there were nine participants whose H and FA equaled 0 or 1 simultaneously, indicating that they might fail to understand the instructions or respond to the experiments with inversed mouse buttons [39]. Consequently, we excluded these nine participants from further analysis, leading to a remaining 51 participants (25 females). Thirdly, we extracted three indices to perform statistical analysis. The corrected hit rate (CHR) was calculated by subtracting FA from H. This correction was conducted to prevent participants' tendency to respond "yes" at the individual level [6,7,9,31]. A larger CHR represented a better memorial performance. The sensitivity and bias were calculated by Equation 4 and Equation 5 from the study of Zhang & Mueller [39]. Due to the small number of trials for each condition (four repetitions for one condition), H and FA might equal 0 or 1. Hence, we calculated the non-parametric signal detection statistics [39,40]. A higher sensitivity represented that participants were more sensitive to the difference between the studied and unstudied stimuli. A weaker bias below one indicated that participants were inclined to respond "yes" for a two-alternative forced choice task; a stronger bias above one indicated that participants were inclined to respond "no" for a two-alternative forced choice task. Finally, after extracting CHR, sensitivity, and bias, we conducted a four-way repeated measures mixed analysis of variance (ANOVA) for each index. The within-subject factors included the sexes of studied stimuli (male and female), emotions of studied stimuli (happy and angry), and instructions (remember and forget); the between-subject factors included the sexes of participants (male and female). As a further analysis, we performed a three-way repeated measures mixed ANOVA for female and male participants, respectively.

2.4. Results

The intuitive results of CHR, sensitivity, and bias of Experiment 1 are depicted separately in three parts of Fig. 2. Within each part, the results for different sexes of studied stimuli and different sexes of participants are drawn separably in four panels. Within each



Note: ' *** ' p<0.001; ' ** ' p<0.01; ' * ' p<0.05.

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Fig. 2. Results of Experiment 1. The results of corrected hit rate (CHR), sensitivity, and bias are shown in parts A, B, and C, respectively. Within each part, the top and bottom panels are the results for female and male studied stimuli, respectively; the left and right panels are the results for female and male participants, respectively. Within each panel, the abscissa represents the emotions of studied stimuli, and the ordinate represents CHR, sensitivity, and bias, respectively. The green and red bars represent the results for "remember" and "forget" instructions, respectively. The error bars represent the standard error of the means across participants.

panel, the abscissa represents the emotions of studied stimuli, and the ordinate represents the corresponding values. The colors of the bars represent different instructions during the study phase. The "*" sign represented the significance between the condition of "remember" instruction and "forget" instruction (the sexes of studied stimuli were pooled). The error bars referred to the standard errors (SE) across 51 participants. The detailed descriptive results are summarized in Table 2. The average values across 51 participants were listed with the corresponding SE written in parentheses.

Regarding CHR (Fig. 2A), we found significantly larger CHR for female stimuli than male stimuli (F (1,49) = 20.75, $p < 0.001$, $\eta_p^2 = 0.30$), for angry stimuli than happy stimuli (F (1,49) = 14.32, $p < 0.001$, $\eta_p^2 = 0.23$), and for female participants than male participants (F (1,49) = 7.96, $p = 0.007$, $\eta_p^2 = 0.14$). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,49) = 6.96, $p = 0.011$, $\eta_p^2 = 0.12$) and between sexes of stimuli and sexes of participants (F (1,49) = 5.99, $p = 0.018$, $\eta_p^2 = 0.11$) were significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,49) = 23.77, $p < 0.001$, $\eta_p^2 = 0.33$) and sexes of participants (F (1,49) = 10.60, $p = 0.002$, $\eta_p^2 = 0.18$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA for different sexes of participants separately. For female participants, we found significantly larger CHR for female stimuli than male stimuli (F (1,24) = 28.95, $p < 0.001$, $\eta_p^2 = 0.55$) and for angry stimuli than happy stimuli (F (1,24) = 16.44, $p < 0.001$, $\eta_p^2 = 0.41$). The remaining effects reached no significance (all $ps > 0.05$). For male participants, we found significantly larger CHR for "remember" instruction than "forget" instruction (F (1,25) = 5.37, $p = 0.029$, $\eta_p^2 = 0.18$) and significant interaction effect between sexes of stimuli and emotions of stimuli (F (1,25) = 6.01, $p = 0.022$, $\eta_p^2 = 0.19$). A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,25) = 7.06, $p = 0.014$, $\eta_p^2 = 0.22$) and instructions (F (1,25) = 5.87, $p = 0.023$, $\eta_p^2 = 0.19$) when female stimuli were presented during the study phase. The remaining effects reached no significance (all $ps > 0.05$). There were three points worthy of notice. First, female participants' identity recognition performance was better than male participants. Second, the direct forgetting phenomenon occurred for male participants, whereas not for female participants. Third, the property of studied stimuli (sexes and emotions) could affect female participants' identity recognition performance, with the worst performance recognizing happy male faces and the best performance recognizing angry female faces. Note that the range of CHR in the current study was comparable with that in the study of Tay & Yang, except that the lower limit of CHR was 0.05 in the current study and 0.17 in the study of Tay & Yang [8]. We presumed that the small CHR might be caused by the small number of trials (4 trials) for each condition in the current study.

Regarding sensitivity (Fig. 2B), we found significantly higher sensitivity for female stimuli than male stimuli (F (1,49) = 6.73, $p = 0.012$, $\eta_p^2 = 0.12$), for angry stimuli than happy stimuli (F (1,49) = 10.47, $p = 0.002$, $\eta_p^2 = 0.18$), and for female participants than male participants (F (1,49) = 7.04, $p = 0.011$, $\eta_p^2 = 0.13$). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,49) = 4.08, $p = 0.049$, $\eta_p^2 = 0.08$) and between sexes of stimuli and sexes of participants (F (1,49) = 6.37, $p = 0.015$, $\eta_p^2 = 0.12$) were significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,49) = 14.18, $p < 0.001$, $\eta_p^2 = 0.22$) and sexes of participants (F (1,49) = 8.99, $p = 0.004$, $\eta_p^2 = 0.16$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA for different sexes of participants separately. For female participants, we found significantly higher sensitivity for female stimuli than male stimuli (F (1,24) = 25.17, $p < 0.001$, $\eta_p^2 = 0.51$) and for angry stimuli than happy stimuli (F (1,24) = 12.41, $p = 0.002$, $\eta_p^2 = 0.34$). The remaining effects reached no significance (all $ps > 0.05$). For male participants, we found significantly higher sensitivity for "remember" instruction than "forget" instruction (F (1,25) = 5.95, $p = 0.022$, $\eta_p^2 = 0.19$) and significant interaction effect between sexes of stimuli and emotions of stimuli (F (1,25) = 4.22, $p = 0.05$, $\eta_p^2 = 0.14$). A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,25) = 4.78, $p = 0.038$, $\eta_p^2 = 0.16$) and instructions (F (1,25) = 5.31, $p = 0.030$, $\eta_p^2 = 0.18$) when female stimuli were presented during the study phase. The remaining effects reached no significance (all $ps > 0.05$). The statistical results of sensitivity were the same as that of CHR. Therefore, there were three points worthy of

Table 2
Descriptive results of Experiment 1. Mean values across participants are listed with the standard errors written in parentheses.

			CHR		Sensitivity		Bias	
			Females	Males	Females	Males	Females	Males
Female stimuli	Happy	Remember	0.32 (0.05)	0.19 (0.06)	0.73 (0.03)	0.61 (0.05)	1.18 (0.11)	1.28 (0.14)
		Forget	0.27 (0.05)	0.06 (0.06)	0.70 (0.03)	0.49 (0.08)	1.18 (0.11)	1.58 (0.20)
	Angry	Remember	0.46 (0.06)	0.25 (0.08)	0.79 (0.03)	0.63 (0.07)	1.02 (0.12)	1.33 (0.16)
		Forget	0.48 (0.05)	0.20 (0.06)	0.81 (0.03)	0.62 (0.06)	1.02 (0.13)	1.30 (0.15)
Male stimuli	Happy	Remember	0.05 (0.05)	0.16 (0.05)	0.54 (0.04)	0.63 (0.04)	1.26 (0.09)	1.36 (0.18)
		Forget	0.15 (0.07)	0.05 (0.04)	0.60 (0.04)	0.55 (0.03)	1.12 (0.08)	1.28 (0.11)
	Angry	Remember	0.20 (0.06)	0.11 (0.05)	0.65 (0.04)	0.59 (0.03)	1.16 (0.12)	1.41 (0.17)
		Forget	0.15 (0.05)	0.08 (0.06)	0.61 (0.04)	0.57 (0.04)	1.22 (0.11)	1.26 (0.11)

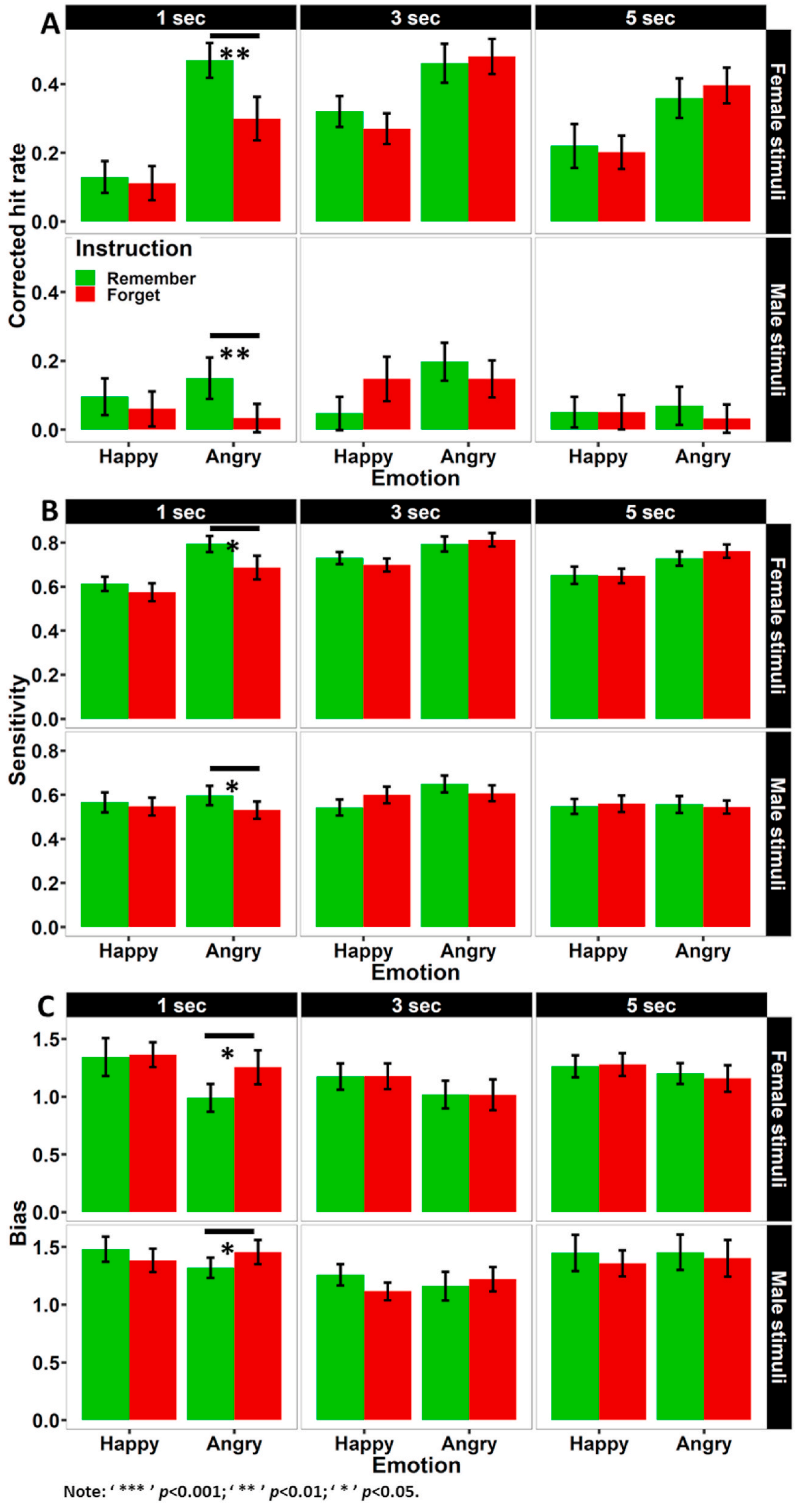

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Fig. 3. Results of Experiment 2. The results of corrected hit rate (CHR), sensitivity, and bias are shown in parts A, B, and C, respectively. Within each part, the top and bottom panels are the results for female and male studied stimuli, respectively; the left, middle, and right panels are the results for conditions of 1 s, 3 s, and 5 s, respectively. Within each panel, the abscissa represents the emotions of studied stimuli, and the ordinate represents CHR, sensitivity, and bias, respectively. The green and red bars represent the results for "remember" and "forget" instructions, respectively. The error bars represent the standard error of the means across participants. Note that the middle panels of a duration of 3 s were the same as the results of female participants in Fig. 2.

notice. First, female participants were more sensitive to discriminating the studied stimulus from the unstudied stimulus than male participants. Second, the instructions could affect the sensitivities of male participants rather than female participants. Third, the property of studied stimuli (sexes and emotions) could affect female participants' sensitivity, with the lowest sensitivity to discriminate happy male faces from other faces and the highest sensitivity to discriminate angry female faces from other faces.

Regarding bias (Fig. 2C), we found that all the effects reached no significance (all $ps > 0.05$). A further ANOVA for female and male participants, respectively, revealed no significant results (all $ps > 0.05$). The results implied that male participants and female participants had the same bias.

To sum up, there were sex differences in DF. Male participants had larger CHR and became more sensitive when instructed to remember the studied stimuli than when instructed to forget the studied stimuli, whereas female participants did not. Furthermore, the sex differences in participants were mainly reflected when female stimuli were presented during the study phase rather than when male stimuli were presented during the study phase. The results supported our first two hypotheses partially. The significant main effects of emotion and sex difference for CHR suggested that the emotion and sex difference could affect DF, whereas the insignificant main effect of instruction suggested that no DF was found for female participants.

Experiment 2. effect of duration during study phase on directed forgetting for female participants

2.5. Objective

Since female participants showed no directed forgetting (DF) in Experiment 1, we focused on female participants in this experiment. According to selective rehearsal theory, participants could rehearse the items irrespective of instructions and further elaborately encode items followed by "remember" instruction, indicating that the processing for items followed by "remember" instruction and "forget" instruction diverged during the study phase [11,12]. We manipulated the durations of items presented during the study phase (1 s and 5 s). If the selective rehearsal theory was held, female participants with superior memorial performance should show DF for a short duration due to insufficient rehearsals to move the working memory into long-term memory.

3. Methods

3.1. Participants and apparatus

We recruited another 60 undergraduates with an average age of 18.2 years old (SD was 0.8 years old, all females). They did not participate in Experiment 1.

The apparatus was the same as that in Experiment 1.

3.2. Stimuli and procedure

The stimuli and procedure were the same as in Experiment 1, except that the duration of stimuli at the study phase was 1 s or 5 s. The experiment was conducted by experimental manipulation with participants randomized. The two conditions of durations (1 s and 3 s) were assigned randomly to two groups of participants (30 each).

3.3. Data analysis

The procedure of extracting CHR, sensitivity, and bias was the same as in Experiment 1. We excluded two participants for the condition of 1 s duration and three participants for the condition of 5 s from further analysis. As a result, there were 28 participants and 27 participants for two conditions of durations, respectively. Since the stimuli and procedure were the same as in Experiment 1, we added the data of 25 female participants obtained from Experiment 1 into the current analysis. After extracting CHR, sensitivity, and bias, we conducted a four-way repeated measures mixed analysis of variance (ANOVA) for each index. The within-subject factors included the sexes of studied stimuli (male and female), emotions of studied stimuli (happy and angry), and instructions (remember and forget); the between-subject factors included the durations of studied stimuli (1 s, 3 s, and 5 s). As a further analysis, we performed a three-way repeated measures mixed ANOVA for the conditions of 1 s and 5 s, respectively. Note that the condition of 3 s had been analyzed in Experiment 1 already.

3.4. Results

The intuitive results of CHR, sensitivity, and bias of Experiment 2 are depicted separately in three parts of Fig. 3. Within each part, the results for different sexes of studied stimuli and different conditions of durations are drawn separably in six panels. Within each panel, the abscissa represents the emotions of studied stimuli, and the ordinate represents the corresponding values. The colors of the bars represent different instructions during the study phase. The "*" sign represented the significance between the condition of "remember" instruction and "forget" instruction (the sexes of studied stimuli were pooled). The error bars referred to the standard errors (SE) across 28 participants for 1 s duration condition and 27 participants for 5 s duration condition. The detailed descriptive results are summarized in Table 3. The average values across 28 participants for 1 s duration condition and 27 participants for 5 s duration condition were listed with the corresponding SE written in parentheses.

Regarding CHR (Fig. 3A), we found significantly larger CHR for female stimuli than male stimuli (F (1,77) = 98.58, $p < 0.001$, $\eta_p^2 = 0.56$) and for angry stimuli than happy stimuli (F (1,77) = 41.98, $p < 0.001$, $\eta_p^2 = 0.35$). Furthermore, the two-factors interaction effect between sexes of stimuli and emotions of stimuli (F (1,77) = 19.78, $p < 0.001$, $\eta_p^2 = 0.20$) was significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,77) = 50.85, $p < 0.001$, $\eta_p^2 = 0.40$) and durations of studied stimuli (F (2,77) = 3.42, $p = 0.038$, $\eta_p^2 = 0.08$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA separately for conditions of 1 s and 5 s. Note that the results of 3 s were the same as in Experiment 1. For a condition of 1 s, we found significantly larger CHR for female stimuli than male stimuli (F (1,27) = 19.09, $p < 0.001$, $\eta_p^2 = 0.41$), for angry stimuli than happy stimuli (F (1,27) = 17.10, $p < 0.001$, $\eta_p^2 = 0.39$), and for "remember" instruction than "forget" instruction (F (1,27) = 8.57, $p = 0.007$, $\eta_p^2 = 0.24$). Furthermore, the interaction effect between sexes of stimuli and emotions of stimuli (F (1,27) = 17.79, $p < 0.001$, $\eta_p^2 = 0.40$) was significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,27) = 26.09, $p < 0.001$, $\eta_p^2 = 0.49$) and instructions (F (1,27) = 6.52, $p = 0.017$, $\eta_p^2 = 0.19$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$). For a condition of 5 s, we found significantly larger CHR for female stimuli than male stimuli (F (1,26) = 66.91, $p < 0.001$, $\eta_p^2 = 0.72$) and for angry stimuli than happy stimuli (F (1,26) = 9.04, $p = 0.006$, $\eta_p^2 = 0.26$). Furthermore, the interaction effects between sexes of stimuli and emotions of stimuli (F (1,26) = 4.99, $p < 0.034$, $\eta_p^2 = 0.16$) were significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,26) = 10.58, $p = 0.003$, $\eta_p^2 = 0.29$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$). There were two points worthy of notice. First, DF occurred for the duration of 1 s, whereas not for longer durations. Second, similar to Experiment 1, the property of studied stimuli (sexes and emotions) could affect female participants' identity recognition performance, with the worst performance recognizing happy male faces and the best performance recognizing angry female faces.

Regarding sensitivity (Fig. 3B), we found significantly higher sensitivity for female stimuli than male stimuli (F (1,77) = 63.03, $p < 0.001$, $\eta_p^2 = 0.45$) and for angry stimuli than happy stimuli (F (1,77) = 25.121, $p < 0.001$, $\eta_p^2 = 0.246$). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,77) = 11.88, $p < 0.001$, $\eta_p^2 = 0.13$) and between instructions and durations (F (2,77) = 3.37, $p = 0.040$, $\eta_p^2 = 0.08$) were significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,77) = 30.62, $p < 0.001$, $\eta_p^2 = 0.28$) and durations of studied stimuli (F (2,77) = 3.74, $p = 0.028$, $\eta_p^2 = 0.09$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA separately for conditions of 1 s and 5 s. For a condition of 1 s, we found significantly higher sensitivity for female stimuli than male stimuli (F (1,27) = 8.98, $p = 0.006$, $\eta_p^2 = 0.25$), for angry stimuli than happy stimuli (F (1,27) = 8.26, $p = 0.008$, $\eta_p^2 = 0.23$), and for "remember" instruction than "forget" instruction (F (1,27) = 8.47, $p = 0.007$, $\eta_p^2 = 0.24$). Furthermore, the interaction effects between sexes of stimuli and emotions of stimuli (F (1,27) = 11.79, $p = 0.002$, $\eta_p^2 = 0.30$) were significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,27) = 13.80, $p < 0.001$, $\eta_p^2 = 0.34$) and instructions (F (1,27) = 5.20, $p = 0.031$, $\eta_p^2 = 0.16$) when female stimuli were presented during the study phase. However, the

Table 3
Descriptive results of Experiment 2. Mean values across participants are listed with the standard errors written in parentheses. Note that the results of a duration of 3 s were the same as those of female participants in Table 2.

			CHR			Sensitivity			Bias		
			1 s	3 s	5 s	1 s	3 s	5 s	1 s	3 s	5 s
Female stimuli	Happy	Remember	0.13 (0.05)	0.32 (0.05)	0.22 (0.06)	0.61 (0.03)	0.73 (0.03)	0.65 (0.04)	1.34 (0.16)	1.18 (0.11)	1.26 (0.10)
		Forget	0.11 (0.05)	0.27 (0.05)	0.20 (0.05)	0.58 (0.04)	0.70 (0.03)	0.65 (0.03)	1.36 (0.11)	1.18 (0.11)	1.28 (0.10)
	Angry	Remember	0.47 (0.05)	0.46 (0.06)	0.36 (0.06)	0.79 (0.04)	0.79 (0.03)	0.73 (0.03)	0.99 (0.12)	1.02 (0.12)	1.20 (0.09)
		Forget	0.30 (0.06)	0.48 (0.05)	0.40 (0.05)	0.69 (0.05)	0.81 (0.03)	0.76 (0.03)	1.26 (0.15)	1.02 (0.13)	1.16 (0.12)
Male stimuli	Happy	Remember	0.10 (0.05)	0.05 (0.05)	0.05 (0.05)	0.57 (0.05)	0.54 (0.04)	0.55 (0.03)	1.48 (0.11)	1.26 (0.09)	1.45 (0.16)
		Forget	0.06 (0.05)	0.15 (0.07)	0.05 (0.05)	0.55 (0.04)	0.60 (0.04)	0.56 (0.04)	1.38 (0.10)	1.12 (0.08)	1.36 (0.11)
	Angry	Remember	0.15 (0.06)	0.20 (0.06)	0.07 (0.06)	0.60 (0.04)	0.65 (0.04)	0.56 (0.04)	1.32 (0.09)	1.16 (0.12)	1.45 (0.15)
		Forget	0.03 (0.04)	0.15 (0.05)	0.03 (0.04)	0.53 (0.04)	0.61 (0.04)	0.54 (0.03)	1.46 (0.11)	1.22 (0.11)	1.40 (0.16)

remaining effects reached no significance (all *ps* > 0.05). For a condition of 5 s, we found significantly higher sensitivity for female stimuli than male stimuli (F (1,26) $= 55.75$, $p < 0.001$, $\eta_p^2 = 0.68$) and for angry stimuli than happy stimuli (F (1,26) $= 6.05$, $p = 0.021$, $\eta_p^2 = 0.19$). However, the remaining effects reached no significance (all *ps* > 0.05). The statistical results of sensitivity were similar to that of CHR. There were two points worthy of notice. First, the instructions could affect the sensitivities of female participants on the condition of 1 s, whereas not on the conditions of longer durations. Second, similar to Experiment 1, the property of studied stimuli (sexes and emotions) could affect female participants' sensitivity, with the lowest sensitivity to discriminate happy male faces from other faces and the highest sensitivity to discriminate angry female faces from other faces.

Regarding bias (Fig. 3C), we found significantly weaker bias for female stimuli than male stimuli (F (1,77) $= 4.01$, $p = 0.049$, $\eta_p^2 = 0.05$) and for angry stimuli than happy stimuli (F (1,77) $= 4.77$, $p = 0.032$, $\eta_p^2 = 0.06$). Furthermore, the two-factors interaction effect between sexes of stimuli and emotions of stimuli (F (1,77) $= 4.65$, $p = 0.034$, $\eta_p^2 = 0.06$) was significant. A simple effect analysis revealed the significant main effect for emotions of stimuli (F (1,77) $= 7.59$, $p = 0.007$, $\eta_p^2 = 0.09$) when female stimuli were presented during the study phase. However, the remaining effects reached no significance (all *ps* > 0.05).

We further conducted the ANOVA separately for conditions of 1 s and 5 s. For a condition of 1 s, we found the significant interaction effects between emotions of stimuli and instructions (F (1,27) $= 4.85$, $p = 0.036$, $\eta_p^2 = 0.15$). A simple effect analysis revealed a significantly weaker bias for "remember" instruction than "forget" instruction on the condition of angry stimuli (F (1,27) $= 6.91$, $p = 0.014$, $\eta_p^2 = 0.20$). However, the remaining effects reached no significance (all *ps* > 0.05). For a condition of 5 s duration, all the effects reached no significance (all *ps* > 0.05). There were two points worthy of notice. First, female participants became more aggressive when instructed to remember the studied angry stimuli than when instructed to forget the studied angry stimuli on a condition of 1 s duration. Second, the property of studied stimuli (sexes and emotions) could affect female participants' biases, with the weakest bias toward angry female faces and the strongest bias toward happy male faces.

To sum up, the effect of duration during the study phase on DF for female participants was mainly reflected for a short duration (1 s). Female participants had larger CHR and became more sensitive when they were instructed to remember the studied stimuli than when they were instructed to forget the studied stimuli on the condition of short duration. Furthermore, the sex differences in stimuli were found, with female stimuli eliciting different CHR and sensitivities for different emotions and durations and male stimuli eliciting nothing. The results could help us examine the third hypothesis. The different results obtained from the conditions of 1 s and 5 s durations suggested that the short duration of items presented during the study phase gave participants less time to remember the stimuli. Hence, the selective rehearsal theory was proved.

Experiment 3. effect of recognition cue during test phase on DF for female participants

3.5. Objective

Since female participants showed DF on a condition of 1 s duration in Experiment 2, we focused on the short duration in this experiment. According to inhibitory control theory, participants could stop the retrieval of items followed by "forget" instruction, indicating that the processing for items followed by "remember" instruction and "forget" instructions diverged during the test phase [13]. We used the recognition cues to provide extra information for participants to facilitate the retrieval of items followed by "forget" instruction. The recognition cues were borders with different colors attached to the stimuli, a method adopted from the study of Taylor et al. [9]. If the inhibitory control theory was held, female participants should show no DF on the condition with recognition cues since the cues with extra information facilitated the retrieval.

4. Methods

4.1. Participants and apparatus

We recruited 50 undergraduates with an average age of 18.3 years old (SD was 0.7 years old, all females). They did not participate in Experiment 1 and Experiment 2.

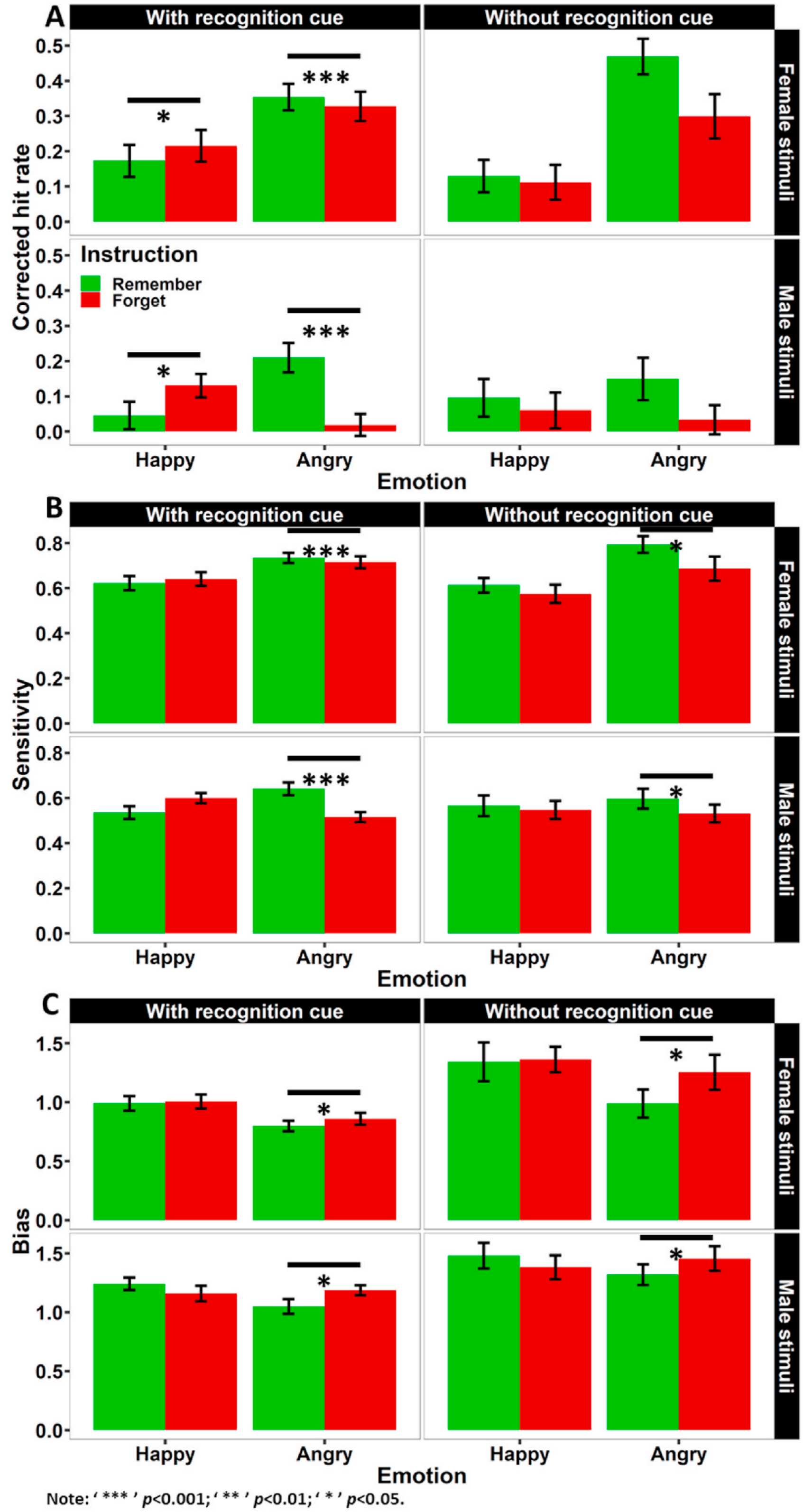
The apparatus was the same as in Experiment 1.

4.2. Stimuli and procedure

The stimuli and procedure were the same as in Experiment 1, except for the followings.

Regarding the test stimuli, we attached three types of recognition cues to the stimuli: black border, green border, and red border Taylor et al. [9]. As shown in the bottom panel in Fig. 1A, the width of the borders was 1 cm. The black border did not provide any information to the participants. A green border meant the stimulus might be presented during the study phase and instructed to remember it. The red border meant the stimulus might be presented during the study phase and instructed to forget it.

Regarding the procedure, the duration of the studied stimuli was 1 s. The experiment was conducted by experimental manipulation. There were three separate blocks for three different recognition cues during the test phase. On the black border block, there were 16 unstudied stimuli, eight studied stimuli with "remember" instructions, and eight studied stimuli with "forget" instructions. On the green border block, there were eight unstudied stimuli and eight studied stimuli with "remember" instructions. On the red border block, there were eight unstudied stimuli and eight studied stimuli with "forget" instructions. At the beginning of each block, the meaning of the recognition cue was provided to the participants. The order of three blocks was counterbalanced among the



(caption on next page)

Fig. 4. Results of Experiment 3. The results of corrected hit rate (CHR), sensitivity, and bias are shown in parts A, B, and C, respectively. Within each part, the top and bottom panels are the results for female and male studied stimuli, respectively; the left and right panels are the results for conditions with and without recognition cues, respectively. Within each panel, the abscissa represents the emotions of studied stimuli, and the ordinate represents CHR, sensitivity, and bias, respectively. The green and red bars represent the results for "remember" and "forget" instructions, respectively. The error bars represent the standard error of the means across participants. Note that the right panels of conditions without recognition cues were the same as the results of 1 s in Fig. 3.

participants. Feedback was given after participants' responses.

4.3. Data analysis

The procedure of extracting CHR, sensitivity, and bias was the same as in Experiment 1. We excluded three participants from further analysis, resulting in the remaining 47 participants. To examine the effect of recognition cue, we added the data of 28 female participants obtained from the condition of 1 s duration in Experiment 2 into the current analysis. After extracting CHR, sensitivity, and bias, we conducted a four-way repeated measures mixed analysis of variance (ANOVA) for each index. The within-subject factors included the sexes of studied stimuli (male and female), emotions of studied stimuli (happy and angry), and instructions (remember and forget); the between-subject factors included the conditions of recognition cues (with and without). As a further analysis, we performed a three-way repeated measures mixed ANOVA for the condition with recognition cues. Note that the condition without recognition cues had been analyzed in Experiment 2 already.

4.4. Results

The intuitive results of CHR, sensitivity, and bias of Experiment 3 are depicted separately in parts A, B, and C of Fig. 4. Within each part, the results for different sexes of studied stimuli and different recognition cues conditions are drawn separately in four panels. Within each panel, the abscissa represents the emotions of studied stimuli, and the ordinate represents the corresponding values. The colors of the bars represent different instructions during the study phase. The "*" sign represented the significance of the main effect for the condition of "remember" instruction and "forget" instruction (the sexes of studied stimuli were pooled). The error bars referred to the standard errors (SE) across 47 participants. The detailed descriptive results are summarized in Table 4. The average values across 47 participants were listed with the corresponding SE written in parentheses.

Regarding CHR (Fig. 4A), we found significantly larger CHR for female stimuli than male stimuli (F (1,73) = 48.37, $p < 0.001$, $\eta_p^2 = 0.40$), for angry stimuli than happy stimuli (F (1,73) = 31.64, $p < 0.001$, $\eta_p^2 = 0.30$), and for "remember" instruction than "forget" instruction (F (1,73) = 8.82, $p = 0.004$, $\eta_p^2 = 0.11$). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,73) = 18.93, $p < 0.001$, $\eta_p^2 = 0.21$) and between emotions of stimuli and instructions (F (1,73) = 15.81, $p < 0.001$, $\eta_p^2 = 0.18$) were significant. A simple effect analysis revealed the significant main effect for emotions of stimuli (F (1,73) = 39.16, $p < 0.001$, $\eta_p^2 = 0.35$) when female stimuli were presented during the study phase; there were the significant main effect for instructions (F (1,73) = 4.71, $p = 0.033$, $\eta_p^2 = 0.06$) and interaction effect between emotions of stimuli and instructions (F (1,73) = 10.85, $p = 0.002$, $\eta_p^2 = 0.13$) when male stimuli were presented during the study phase. The results indicated the DF phenomenon when angry stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA for the condition with recognition cues. Note that the results for conditions without recognition cues were the same as in Experiment 2. We found significantly larger CHR for female stimuli than male stimuli (F (1,46) = 32.50, $p < 0.001$, $\eta_p^2 = 0.41$) and for angry stimuli than happy stimuli (F (1,46) = 13.47, $p < 0.001$, $\eta_p^2 = 0.23$). Furthermore, the interaction effects between sexes of stimuli and emotions of stimuli (F (1,46) = 4.70, $p = 0.035$, $\eta_p^2 = 0.09$) and between emotions of stimuli and instructions (F (1,46) = 18.21, $p < 0.001$, $\eta_p^2 = 0.28$) were significant. A simple effect analysis revealed a significantly smaller CHR for "remember" instruction than "forget" instruction on the condition of happy stimuli (F (1,46) = 4.35, $p = 0.043$, $\eta_p^2 = 0.09$); there was a significantly larger CHR for "remember" instruction than "forget" instruction on the condition of angry stimuli (F (1,46) = 14.03, $p < 0.001$, $\eta_p^2 = 0.23$). Also, the interaction effect between sexes of stimuli and instructions on the condition of angry stimuli was significant

Table 4
Descriptive results of Experiment 3. Mean values across participants are listed with the standard errors written in parentheses. Note that the results of conditions without recognition cues were the same as the results of 1 s in Table 3.

			CHR		Sensitivity		Bias	
			With	Without	With	Without	With	Without
Female stimuli	Happy	Remember	0.17 (0.05)	0.13 (0.05)	0.62 (0.03)	0.61 (0.03)	0.99 (0.06)	1.34 (0.16)
		Forget	0.22 (0.05)	0.11 (0.05)	0.64 (0.03)	0.58 (0.04)	1.01 (0.06)	1.36 (0.11)
	Angry	Remember	0.35 (0.04)	0.47 (0.05)	0.73 (0.02)	0.79 (0.04)	0.80 (0.05)	0.99 (0.12)
		Forget	0.33 (0.04)	0.30 (0.06)	0.72 (0.03)	0.69 (0.05)	0.86 (0.05)	1.26 (0.15)
Male stimuli	Happy	Remember	0.05 (0.04)	0.10 (0.05)	0.54 (0.03)	0.57 (0.05)	1.24 (0.05)	1.48 (0.11)
		Forget	0.13 (0.03)	0.06 (0.05)	0.60 (0.02)	0.55 (0.04)	1.16 (0.07)	1.38 (0.10)
	Angry	Remember	0.21 (0.04)	0.15 (0.06)	0.64 (0.03)	0.60 (0.04)	1.05 (0.06)	1.32 (0.09)
		Forget	0.02 (0.03)	0.03 (0.04)	0.52 (0.02)	0.53 (0.04)	1.19 (0.04)	1.46 (0.11)

(F (1,46) = 6.69, p = 0.013, η_p^2 = 0.13). The results indicated that DF was more obvious when the angry male stimuli were presented during the study phase than when the angry female stimuli were presented. However, the remaining effects reached no significance (all $ps > 0.05$). There were two points worthy of notice. First, DF could occur for the condition with recognition cues but with different forms. DF occurred on the condition of angry stimuli for female participants, whereas the reversed DF occurred on the condition of happy stimuli for female participants. Second, the property of studied stimuli (sexes and emotions) could affect female participants' identity recognition performance, with the worst performance recognizing happy male faces and the best performance recognizing angry female faces.

Regarding sensitivity (Fig. 4B), we found significantly higher sensitivity for female stimuli than male stimuli (F (1,73) = 33.66, $p <$ 0.001, η_p^2 = 0.32), for angry stimuli than happy stimuli (F (1,73) = 20.68, $p <$ 0.001, η_p^2 = 0.22), and for "remember" instruction than "forget" instruction (F (1,73) = 8.68, p = 0.004, η_p^2 = 0.11). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,73) = 15.43, $p <$ 0.001, η_p^2 = 0.18) and between emotions of stimuli and instructions (F (1,73) = 10.85, p = 0.002, η_p^2 = 0.13) were significant. A simple effect analysis revealed the significant main effect for emotions of stimuli (F (1,73) = 27.63, $p <$ 0.001, η_p^2 = 0.28) when female stimuli were presented during the study phase; there was a significant interaction effect between emotions of stimuli and instructions (F (1,73) = 9.55, p = 0.003, η_p^2 = 0.12) when male stimuli were presented during the study phase. The results indicated the different sensitivities for different instructions when angry stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA for the condition with recognition cues. We found significantly higher sensitivity for female stimuli than male stimuli (F (1,46) = 31.95, $p <$ 0.001, η_p^2 = 0.41) and for angry stimuli than happy stimuli (F (1,46) = 11.99, p = 0.001, η_p^2 = 0.21). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,46) = 5.21, p = 0.027, η_p^2 = 0.10) and between emotions of stimuli and instructions (F (1,46) = 14.21, $p <$ 0.001, η_p^2 = 0.24) and three-factors interaction effects among sexes of stimuli, emotions of stimuli and instructions (F (1,46) = 4.39, p = 0.042, η_p^2 = 0.09) were significant. A simple effect analysis revealed a significantly stronger sensitivity for "remember" instruction than "forget" instruction on the condition of angry stimuli (F (1,46) = 13.23, $p <$ 0.001, η_p^2 = 0.22). Also, the interaction effect between sexes of stimuli and instructions on the condition of angry stimuli was significant (F (1,46) = 6.35, p = 0.015, η_p^2 = 0.12). The results indicated that DF was more obvious when the angry male stimuli were presented during the study phase than when the angry female stimuli were presented. However, the remaining effects reached no significance (all $ps > 0.05$). The statistical results of sensitivity were similar to that of CHR. There were two points worthy of notice. First, the instructions could affect the sensitivities of female participants irrespective of the conditions of recognition cues. Second, similar to Experiment 1 and Experiment 2, the property of studied stimuli (sexes and emotions) could affect female participants' sensitivity, with the lowest sensitivity to discriminate happy male faces from other faces and the highest sensitivity to discriminate angry female faces from other faces.

Regarding bias (Fig. 4C), we found significantly weaker bias for the condition with recognition cues than the condition without recognition cues (F (1,73) = 20.53, $p <$ 0.001, η_p^2 = 0.22), for female stimuli than male stimuli (F (1,73) = 12.934, $p <$ 0.001, η_p^2 = 0.151), and for angry stimuli than happy stimuli (F (1,73) = 13.64, $p <$ 0.001, η_p^2 = 0.16). Furthermore, the two-factors interaction effects between sexes of stimuli and emotions of stimuli (F (1,73) = 4.16, p = 0.045, η_p^2 = 0.05) and between emotions of stimuli and instructions (F (1,73) = 8.66, p = 0.004, η_p^2 = 0.11) were significant. A simple effect analysis revealed the significant main effects for emotions of stimuli (F (1,73) = 10.96, p = 0.001, η_p^2 = 0.13) and conditions of recognition cues (F (1,73) = 12.48, $p <$ 0.001, η_p^2 = 0.15) when female stimuli were presented during the study phase; there were the significant main effect for conditions of recognition cues (F (1,73) = 9.87, p = 0.002, η_p^2 = 0.12) and interaction effect between emotions of stimuli and instructions (F (1,73) = 7.01, p = 0.010, η_p^2 = 0.09) when male stimuli were presented during the study phase. The results indicated the different biases for different instructions when angry stimuli were presented during the study phase. However, the remaining effects reached no significance (all $ps > 0.05$).

We further conducted the ANOVA for the condition with recognition cues. We found significantly weaker bias for female stimuli than male stimuli (F (1,46) = 33.61, $p <$ 0.001, η_p^2 = 0.42) and for angry stimuli than happy stimuli (F (1,46) = 16.30, p = 0.001, η_p^2 = 0.26). However, the remaining effects reached no significance (all $ps > 0.050$). There were two points worthy of notice. First, female participants became more aggressive when recognition cues were attached to the test stimuli than when no recognition cues were attached to the test stimuli. Second, the property of studied stimuli (sexes and emotions) could affect female participants' biases, with the weakest bias toward angry female faces and the strongest bias toward happy male faces.

To sum up, the recognition cues could not affect DF, whereas the cues could alter female participants' biases. Female participants were more inclined to respond "yes" when there were recognition cues than when there were no recognition cues. Furthermore, DF occurred when angry stimuli were presented during the study phase, whereas not when happy stimuli were presented during the study phase. The results could help us examine the third hypothesis. The insignificant main effect of recognition cues for CHR suggested that the attached cues could not enhance the retrieval of items followed by "forget" instruction. Hence, the inhibitory control theory was not proved.

4.5. General results

So far, we have analyzed the factors that could affect corrected hit rate (CHR), sensitivity, and bias in three experiments separately. We found that the factors that affected participants' sensitivities were similar to those that affected participants' CHR. To confirm such a finding, we performed the non-parametric Spearman correlation analyses to examine the relationship between any two parameters. The Holm-adjusted significance level is set as 0.05. The correlation analysis was conducted on female and male participants separately in Experiment 1, on conditions of 1 s and 5 s separately in Experiment 2, and on condition with recognition cues in Experiment 3. The results of correlation matrices calculated by the R package "ggstatsplot" are depicted in Fig. 5A–E [41].

As shown in Fig. 5, we found that participants' sensitivities were highly correlated with CHR (a coefficient of 0.97 at least) under any conditions. The higher sensitivity was, the larger CHR was. On the other hand, participants' biases seemed not, and if any, weakly correlate with CHR except for the condition with recognition cues, wherein bias was moderately correlated with CHR (a coefficient of −0.54).

4.6. General discussion

We conducted three experiments and used facial stimuli as the items in the item-method paradigm to examine the effects of emotion and sex difference on directed forgetting (DF). In Experiment 1, female and male participants were recruited. In Experiment 2, the durations of items presented during the study phase were manipulated, and only female participants were recruited. In Experiment 3, the existence of recognition cues attached to the items presented during the test phase was manipulated, and only female participants were recruited. To statistically analyze the results, we calculated corrected hit rate (CHR) to represent participants' memorial performances and sensitivity and bias to represent participants' perceptions. The important conclusions could be summarized as the followings: (a) female participants owned superior memorial performances than male participants; (b) female participants could recognize the angry female faces with the best performance and happy male faces with the worst performance; (c) male participants could intentionally forget faces more easily than female participants; (d) female participants could intentionally forget faces that lasted for a short duration, whereas they could not forget a long-lasting face; (e) with the aid of outside help, female participants became more aggressive and could intentionally forget angry faces, especially for the angry male faces; (f) participants' sensitivities were strongly correlated with their memorial performances, whereas their biases gave almost no information about the performance. Our results supported the first two hypotheses: emotions and sex differences could affect DF, and there was an interaction effect between emotions and sex differences. Our results also supported the third hypothesis by proving the selective rehearsal theory rather than the inhibitory

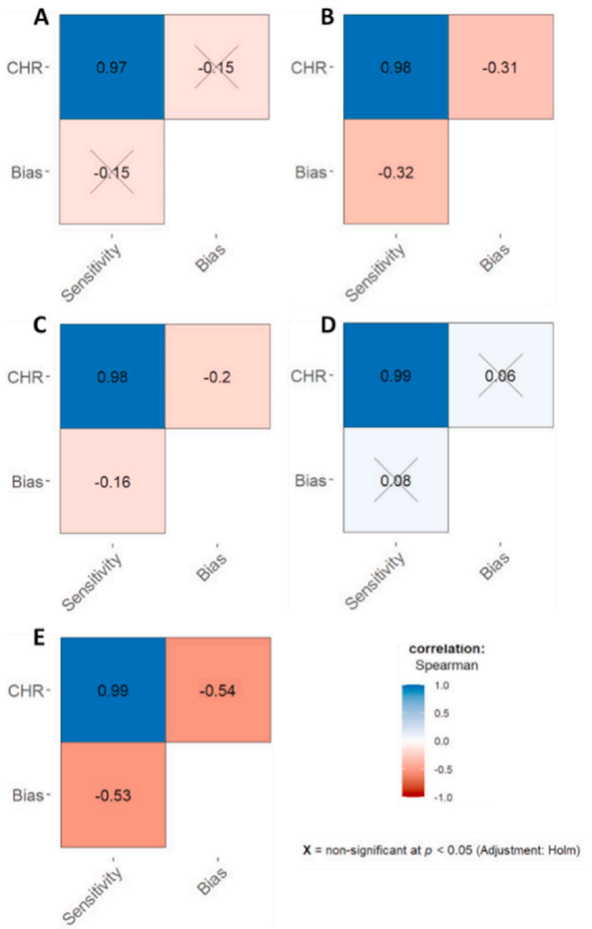


Fig. 5. Correlation matrices for three experiments. Panel A: male participants in Experiment 1; panel B: female participants in Experiment 1; panel C: a condition of 1 s duration in Experiment 2; panel D: a condition of 5 s duration in Experiment 2; panel E: a condition with recognition cues in Experiment 3. Within each panel, the correlation coefficients between any two variables chosen from CHR, sensitivity, and bias are shown, with the colors representing the corresponding p values. A big cross on the correlation coefficients is added if the correlation coefficient is insignificant ($p > 0.05$).

control theory.

Regarding CHR, we found that female participants owned significantly larger CHR for female stimuli than male stimuli and for angry stimuli than happy stimuli, irrespective of any manipulations (Experiment 1, Experiment 2, and Experiment 3). Furthermore, female participants owned significantly larger CHR than male participants (Experiment 1). Our results indicated that female participants could easily recognize the angry female faces with the best performance, whereas male participants struggled to recognize the happy male faces with the worst performance. The sex differences in participants and stimuli were consistent with previous studies, especially the own-gender bias found by Lovén et al. [19–21,42,43]. However, the interaction between emotion and sex seemed contradictory to previous studies, with links between anger with females and happiness with males in the current study and links between anger with males and happiness with females in the previous studies [8,29,30,44,45]. There are several possible reasons. Firstly, the facial stimuli in the current study were cropped to include no cues of sex (such as hairs), whereas no such operation was implemented in the study of Tay & Yang [8]. Our results were not exclusive. There were studies reporting the links between anger with females and happiness with males [46,47]. Therefore, it is possible that the different manipulations of facial stimuli elicited the inconsistency. Secondly, it has been shown that the angry female faces were more difficult to detect than other faces, indicating that participants should assign more cognitive sources to recognize them [48]. Since females owned superior memorial performances, the increased difficulty recognizing angry female faces might not impair but enhance the performance, leading to larger CHR. Thirdly, we recruited only female participants, whereas previous studies recruited female and male participants. Although the social gender role is generally accepted from the evolutionary perspective, females become more self-awakening due to the advocacy of feminism. Since the participants in our study were born after 2000 years, they might be against the stereotype of female roles and advocate the idea that females can be strong and agentive instead of caring and submissive.

Regarding DF, we found that male participants had larger CHR when they were instructed to remember rather than forget the items (Experiment 1). However, the DF was more complicated for female participants. Female participants had larger CHR when they were instructed to remember rather than forget the items on the condition of 1 s duration for items during the study phase. There was no DF on the conditions of 3 s and 5 s durations. Furthermore, we reported the DF on the condition with recognition cues during the test phase. We found the DF for angry stimuli and reversed DF for happy stimuli. Also, even among the angry stimuli, the DF was more pronounced for male than female stimuli. As shown in our results and previous studies, female participants owned better memorial performances than male participants and even better performances when recognizing female faces than male faces [11,19,21,42,43]. Therefore, it was difficult to forget the items followed by "forget" instruction for female participants and female stimuli, resulting in the absence of DF in Experiment 1 and attenuation of DF for female stimuli in Experiment 3. The finding about the reversed DF for happy stimuli on the condition with recognition cues seemed intriguing and needed to be verified in the future.

Our results supported the selective rehearsal theory to explain the DF phenomenon for female participants, which was consistent with previous studies [9,11,12]. Selective rehearsal theory implied that cognitive processing occurred during the study phase rather than the test phase. By rehearsing the items in the working memory, participants could maintain the items irrespective of the following instructions. Further processing would be commenced for the "remember" instruction and halted for the "forget" instruction. In Experiment 2, we found that the DF got attenuated for longer durations (3 s and 5 s) of items during the study phase. As the duration of items became longer, the items were rehearsed enough times to move into the long-term memory; thus, the items followed by "forget" instruction became more resistant to forgetting, especially for female participants who owned superior memorial performances [32–35]. Moreover, we reported DF for the condition with recognition cues during the test phase in Experiment 3. If the inhibitory control theory was held, there would be an attenuated DF effect for the condition with recognition cues due to the facilitated retrieval of items followed by "forget" items, which was not the case in the current study. However, it was worth noting that although our results supported selective rehearsal theory exclusively, the inhibitory control theory might still play a role. By combining EEG with the item-method DF paradigm, previous studies have reported that selective rehearsal theory and inhibitory control theory could account for the item-method DF with different temporal profiles [49,50].

Regarding sensitivity, we got the same results with CHR. Simply speaking, female participants were better at discriminating against female stimuli than male stimuli and angry stimuli than happy stimuli. Furthermore, female participants were more sensitive than male participants. This was further verified by the correlation analysis in the general results (Fig. 5). We found a significantly positive relationship between sensitivity and CHR, with a coefficient at least reaching 0.97. Our results were inconsistent with that of Tay & Yang, wherein stronger sensitivity was reported for male stimuli than female stimuli [8]. We recruited only female participants, whereas Tay & Yang recruited female and male participants [8]. Also, we presumed that the cropped facial stimuli without sex cues in the current study might elicit a stronger representation of female stimuli than male stimuli in memory, leading to discrepant results about sensitivity. Nevertheless, we argued that sensitivity was a reliable index for evaluating participants' performances.

Regarding bias, we found that female and male participants had the same biases with the same tendency toward responding "yes" in the current study (Experiment 1). Moreover, female participants became more aggressive when instructed to remember the angry stimuli than when instructed to forget the angry stimuli on the condition of 1 s duration (Experiment 2). Also, the recognition cues could lower female participants' biases, leading to a stronger tendency to respond "yes" (Experiment 3). Previous studies have shown that manipulations of experiments and properties of stimuli could adjust participants' biases [51–53]. For example, Dougal & Rotello found that negative arousal stimuli could make participants more aggressive than neutral and positive arousal stimuli [51]. According to the correlation analysis in the general results (Fig. 5), we found that bias was negatively related to CHR, albeit the relationship was not strong enough, with a rather moderate or even insignificant coefficient. A previous study has reported that personal traits might not affect DF [54]. As a result, we argued that bias seemed unlikely to take effect in the item-method DF paradigm.

There are some limitations in the study. First, we aimed to examine the effect of emotion on DF. We chose facial stimuli with different emotions, whereas participants' emotions were not controlled. We should ask participants to rate their emotions during the following experiments. Second, although our results supported the selective rehearsal theory behaviorally, the lack of physiological experiments made our conclusions superficial. In the future, experiments with event-related potential techniques can be conducted to examine at what stage emotion and sex difference have an impact on DF physiologically. Third, the number of trials for each condition was too small (four trials for each), which might lead to a small CHR (for example, 0.05 in Table 2) for some conditions. Forth, we deployed the between-subject experimental designs for the condition of durations during the study phase in Experiment 2 and the condition of recognition cues during the test phase in Experiment 3. We can conduct within-subject experiments to preclude the possible effects of individual differences in the future. Fifth, we analyzed the same data across multiple experiments. For example, we treated the condition of female participants in Experiment 1 as a condition in Experiment 2. We may consider recruiting more participants in Experiment 2 to recollect data in the future. In so doing, we can further compare the results collected at different times. Sixth, we recruited only female participants in Experiment 2 and Experiment 3. Therefore, the conclusions from the current study might not be generalized to male participants and should be treated cautiously.

Nevertheless, our results implied a twofold thing for the following studies. First, the sex difference existed in self and others. Therefore, researchers should simultaneously consider the sexes of participants and visual stimuli when studying people's memory and forgetting. Second, the sensitivity of participants and the emotion of visual stimuli also affected people's memory and forgetting. Therefore, researchers should consider the attributes of participants and stimuli. As to the practical application, our results suggested controlling people's memory by manipulating an event's attributes (duration and emotion). We found that females might struggle to forget faces they wish to forget due to their better memorial performances and stronger sensitivities than males. Although females could intentionally forget faces with only brief exposures before, the duration of exposure could not be altered. It is intriguing to dig into DF more to find out what manipulations during the study phase could be used to make females forget things they wish to forget.

Author contribution statement

Xiaolei Song; Xiaofei Hu: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Feng Yi; Meimei Dong: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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