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Article

Disentangling the Effects of Backward/Forward Associative Strength and Theme Identifiability in False Memory

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ABSTRACT

Background: False memory has been extensively studied using the Deese/Roediger-McDermott paradigm. Despite the robustness of the effect, there is wide variability in the results, which is not fully understood. **Method:** Three experiments independently examined the role of backward associative strength (BAS), forward associative strength (FAS), and theme identifiability (ID) on false memories. In Experiment 1, lists varied in BAS while controlling FAS and ID. In Experiment 2, FAS was manipulated while BAS and ID were controlled. Finally, in Experiment 3, lists varied in ID while controlling BAS and FAS. Data was analyzed using both frequentist and Bayesian analyses. **Results:** We found false memories in all three experiments. Specifically, false recognition was higher in high-BAS than in low-BAS lists in Experiment 1. In Experiment 2, false recognition was higher in high-FAS than in low-FAS lists. In Experiment 3, false recognition was lower in high-ID than in low-ID lists. **Conclusions:** These findings suggest that both BAS and FAS—variables that promote error-inflating processes—and ID—which promotes error-editing processes—contribute independently to the production of false memories. Splitting apart the role of these variables helps to understand the variability of false memories and to extrapolate DRM tasks to explore other cognitive domains.

Aislando el Papel de la Fuerza Asociativa Directa e Inversa y la Identificabilidad del Tema Sobre los Recuerdos Falsos

Palabras clave:
Memorias falsas
Paradigma DRM
Fuerza asociativa inversa
Fuerza asociativa directa
Identificabilidad

RESUMEN

Antecedentes: las memorias falsas se han estudiado ampliamente utilizando el paradigma Deese/Roediger-McDermott. A pesar de la robustez del efecto, existe una amplia variabilidad de resultados que todavía no se comprende completamente. **Método:** tres experimentos examinaron independientemente el papel de la fuerza asociativa inversa (BAS), fuerza asociativa directa (FAS) e identificabilidad del tema (ID) en el reconocimiento falso (RF). Primero, se manipuló el BAS mientras se controló FAS e ID (Experimento 1). Segundo, se manipuló el FAS mientras se controló BAS e ID (Experimento 2). Finalmente, se manipuló ID mientras se controló BAS y FAS (Experimento 3). Se utilizaron análisis frecuentistas y bayesianos. **Resultados:** el RF fue mayor en las listas de alto que bajo BAS (Experimento 1), y alto que bajo FAS (Experimento 2). En cambio, el RF fue menor en las listas de alto ID que bajo ID (Experimento 3). **Conclusiones:** tanto BAS como FAS, variables que promueven procesos de inflación del error, pero también ID, quien promueve procesos de edición del error, contribuyen de forma independiente a la producción de memorias falsas. Aislar el papel de estas variables ayuda a comprender la variabilidad de los falsos recuerdos y a extrapolar las tareas DRM para explorar otros dominios cognitivos.

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The study of memory errors has gained much attention in the past decades (for reviews, see Gallo, 2010; Otgaar et al., 2022). The Deese/Roediger–McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995) has been the most frequently used paradigm to study false memories in a controlled laboratory setting. In this paradigm, participants study lists of words (e.g., waves, shore, bay, coast, swim, port) associated with a non-presented critical lure (e.g., SEA). In a subsequent memory test, the critical lures are often falsely recalled or recognized, resulting in a robust false memory effect across a variety of experimental manipulations (Arndt, 2010; Boldini et al., 2013; Coane et al., 2021; Del Prete et al., 2014; Gallo et al., 1997, 2001; McCabe & Smith, 2002; Multhaup & Conner, 2002; Schopen et al., 2022; Wang et al., 2019; Watson et al., 2004).

False memory rates obtained with the DRM paradigm vary widely, and researchers in the area have long been intrigued by this puzzling variability. Some authors have explored individual differences on false memory production (Arndt & Beato, 2017; Beato, Cadavid, et al., 2013; Beato, Pulido, et al., 2013; Beato & Arndt, 2021b; Malloggi et al., 2022; Suarez & Beato, 2021; Ulatowska et al., 2021), whereas others have analyzed the associative/semantic structure of the lists (Beato & Arndt, 2021a; Brainerd et al., 2020; Cadavid et al., 2021; Fam et al., 2021). The present research is framed within the last line of research.

The two major frameworks used to account for the false-memory illusion in the DRM paradigm are the activation-monitoring framework (Roediger et al., 2001) and the fuzzy-trace theory (Brainerd & Reyna, 2002; Reyna & Brainerd, 1995). Both theoretical approaches differ in the mechanisms underlying false memory formation (for further details, see Brainerd & Reyna, 2005; Gallo, 2010; Roediger et al., 2001). However, to explain the production of false memories, the activation-monitoring framework and the fuzzy-trace theory converge in postulating the existence of two opposing processes: error-inflating processes and error-editing processes. Error-inflating processes would increase the likelihood of committing a false memory, and the error-editing processes would counteract the false memory commission (Arndt & Gould, 2006; Cadavid & Beato, 2016; Carneiro et al., 2014).

Previous research has identified variables that affect error-inflating processes (e.g., pre-existing associations between studied words and the critical lure) and variables that facilitate error-editing processes (e.g., easily identifiable critical lures). However, as we explain further below, due to the DRM materials usually employed, the reported effects of those variables might be confounded among them. Hence, there is scarce research on the role of "pure" variables that promote error-inflating and error-editing processes. The present research aims to systematically and independently explore the role of three variables that have been frequently cited as explanatory of false memory in the DRM paradigm. Specifically, we explored two variables related to error-inflating processes (i.e., backward associative strength or BAS and forward associative strength or FAS) and one variable related to error editing processes (i.e., identifiability of the critical lure or ID).

Among the variables that increase false memories, the associative strength from the studied items to the critical lure (i.e., BAS) is the most commonly cited. The effect of BAS on false memories seems straightforward: during encoding, the existing associations between the studied items and the critical lure are activated, which in turn activates the critical lure representation. A substantial body of research has found that critical lures from lists with high BAS are more likely to be falsely recalled (Deese, 1959; Gallo & Roediger, 2002; McEvoy et al., 1999; Roediger et al., 2001) and recognized (Arndt & Gould, 2006; Beato & Arndt, 2017) in a posterior memory test. However, there is evidence that DRM lists with low association also produce false memories (Beato & Arndt, 2017; Cadavid et al., 2012; Cadavid & Beato, 2017; Knott et al., 2012).

A thorough analysis of the lists' characteristics from most previous studies indicates that the effect of BAS might be confounded with other variables (e.g., Gallo & Roediger, 2002). For instance, associations in our mental lexicon tend to be bi-directional. In other words, not only are studied items associated with the critical lures, but the critical lures are also associated with the studied items. In that sense, BAS is strongly related to the associative strength from the critical lure to the studied words, which is typically referred to as forward associative strength (i.e., FAS; Brainerd et al., 2008). Due to the bidirectional nature of the associative processes, some studies have manipulated BAS while controlling FAS, and they have found that BAS influenced false memories even when it is not confounded by FAS (Arndt, 2012, 2015; Beato & Arndt, 2017; Cadavid & Beato, 2017).

Previous research has also examined the role that FAS (i.e., associative strength from the critical lure to the studied items) plays on false memories and their outcomes are mixed. Some studies have failed to find a significant correlation between FAS and false recall or recognition rates (Beato & Arndt, 2021b; Gallo & Roediger, 2002; Roediger et al., 2001). However, when FAS and BAS were independently manipulated in factorial designs, they both affected the magnitude of the DRM illusion, showing higher false recognition rates for high than for low BAS and FAS lists (Brainerd & Wright, 2005; Cadavid et al., 2012; Howe et al., 2009).

As mentioned before, this study also focused on one variable that has proven to influence error-editing processes: theme identifiability or ID (Carneiro et al., 2011, 2012, 2014; Neuschatz et al., 2003). This concept refers to how easily participants are able to identify the critical lure from the associates of the list (Beato & Cadavid, 2016). Participants can use identifiability to guide their decision process during the memory task, which is why ID is an interesting variable to explore error-editing processes. When participants are able to identify the critical lure/s of the list, chances are that they do not commit the false memory. Indeed, previous research has shown that critical lures that are easily identifiable are less likely to be claimed as a studied item (Carneiro et al., 2009, 2012). However, a previous study showed that theme identifiability and BAS correlate (Beato & Cadavid, 2016). Therefore, it is critical to tear apart ID from BAS to understand the role of theme identifiability in reducing false memory. As BAS increases, the critical lure receives more activation from the pre-existing associations between the studied items and the critical lure. It seems straightforward to think that a highly activated critical lure is more likely to be identified. Tearing apart the effect of ID from BAS is not an easy experimental control to exert and, to our knowledge, only one DRM study has attempted this, comparing high-ID and low-ID lists with non-different BAS levels (Carneiro & Fernandez, 2013). Again, in that study, high-ID lists showed lower levels of false recall than low-ID lists, but FAS values were not controlled.

To sum up, to date, there is research that has explored the role of BAS, FAS, and ID on false memory raised with the DRM paradigm. However, no previous research has explored the role of each one of these variables on false memory while simultaneously controlling the other two, so the reported effects of BAS, FAS, and ID on false memory might be confounded. Hence, there is a need for research to explore the role of each of these variables separately (i.e., BAS, FAS, and ID) as it will allow us to disentangle the contribution of each of them in the production of false memories in the DRM paradigm. To this aim, it is necessary to exert strict controls over the materials, which is not an easy task, but a needed one to advance the theoretical knowledge about the mechanisms underlaying false memory.

In this research, for the first time in the literature, three experiments aimed to disentangle the role of (1) BAS (Experiment 1) while controlling FAS and ID, (2) FAS (Experiment 2) while controlling BAS and ID, and (3) ID (Experiment 3) while controlling BAS and FAS. In other words, in Experiment 1 we selected two groups of DRM lists that differed in their BAS values (i.e., lists with high-BAS values and lists with low-BAS values). Besides considering the BAS values, we also made sure that those two groups of lists did not differ in terms of FAS and ID values. This way we can analyze the effect of BAS on false memory independently of FAS and ID. For its part, in Experiment 2 we exert a similar control but this time selecting two groups of lists that differed in FAS values (i.e., high-FAS lists and low-FAS lists), while they did not differ in their BAS and ID values. Finally, in Experiment 3, two groups of DRM lists that differed in terms of ID (i.e., high-ID lists and low-ID lists) were selected. Moreover, these two groups of lists did not differ in their BAS and FAS values. We used both frequentist and Bayesian analyses to provide a clearer picture of the phenomena under study.

Experiment 1

According to previous research within the DRM paradigm, higher levels of backward associative strength (BAS) produce more false memory (e.g., Roediger et al., 2001). In this Experiment, we compared lists with high and low BAS while exerting strict control over FAS and ID levels (see Table 1). We hypothesized that high-BAS lists would produce more false memory than low-BAS lists, just as past research suggests.

Method

Participants

Eighty-two undergraduate students (91.46% women) participated voluntarily in exchange for course credit. According to Brysbaert (2019, p.25), 75 participants are necessary to detect a medium size effect (d = .50) in the interaction of a 2 x 2 repeated-measures ANOVA. All participants were native Spanish speakers, and their ages ranged from 19 to 26 years (M = 19.88, SD = 1.43). The Bioethics Committee at the University of Salamanca approved this study.

Instruments

This study used 16 DRM lists composed of a critical lure and six associatively related words based upon backward associative strength (see Table 2). The lists were obtained from a previous normative study (Beato & Cadavid, 2016). BAS values for each list were calculated as the mean of the associative strength of its six associates to the critical lure. FAS and ID values per critical word were determined following the same criteria. Eight lists were selected to have high-BAS values (M = .28, SD = .06) and the other eight were selected to have low-BAS values (M = .05, SD = .01). The backward associative strength of the high- and low-BAS lists differed significantly, $t(7.35) = 10.89$, $p < .001$, Cohen's d = 5.45, 95% CI [2.54, 8.32]. Lists were chosen so that high- and low-BAS lists showed no significant differences regarding FAS, $t(14) = 0.02$, p = .985, Cohen's d = 0.01, 95% CI [-0.97, 0.99], nor ID values, $t(14) = 0.14$, p = .891, Cohen's d = 0.07, 95% CI [-0.91, 0.05]. In other words, neither FAS nor ID differed significantly between high- and low-BAS lists.

From the pool of 16 DRM lists, 10 were used in the study phase, half with high-BAS values and the other half with low-BAS values. The remaining six DRM lists served as distractors on the recognition memory test. Specifically, unrelated-critical distractors were the critical lures from the non-studied lists, and unrelated distractors were the associated words in the non-studied lists. Three versions of the experimental task were created so that all lists served as both studied and distractor lists. The recognition memory test was composed of 80 words: 40 studied words (four per study list, serial positions, 1, 3, 4, and 6), 10 critical lures (one per study list), and 30 words from the distractor lists (24 unrelated distractors, serial positions 1, 3, 4, and 6 of the associates of the distractor lists, and six unrelated-critical distractors, the critical lure of each distractor list). Stimuli were presented using E-Prime 2.0 (Schneider et al., 2012).

Procedure

Participants were assessed in groups of up to 24 and were equally distributed across the three versions of the experimental task. They signed a written informed consent prior to beginning the study. Instructions were presented on the computer screen and read aloud by the experimenter.

In the study phase, participants studied 60 words (10 lists of six words: 5 high-BAS lists, 5 low-BAS lists) and were informed that there would be a subsequent memory test. Each word was visually presented for 2,000 ms in the center of the computer monitor in lower case letters in black against a white background. A 500 ms interstimulus interval was included between each word. The order of the lists was randomized for each participant.

Following the study phase, participants performed 30-minute working memory distractor tasks. Specifically, they were presented with two subsets from the Wechsler Adult Intelligence Scale (WAIS-IV): Digit Span and Letter-Number Sequencing (Wechsler, 2012). Feedback on accuracy was given individually at the end of each task.

After the 30-minute delay, participants were administered the self-paced recognition memory test. They were informed that they would be presented with words one at a time on the center of the computer monitor and they had to decide whether each word was presented during the study phase (i.e., old item) or not (i.e., new item), by pressing the corresponding key on the keyboard (key "E" for old items, key "N" for new items). Items were presented in random order.

Table 1.
Mean Backward Associative Strength (BAS), Forward Associative Strength (FAS), And Theme Identifiability (ID) of the Lists Used in Experiments 1, 2, And 3.

	Lists	BAS	FAS	ID
Experiment 1	High BAS	0.28 (0.06)	0.01 (0.01)	0.49 (0.32)
	Low BAS	0.05 (0.01)	0.01 (0.01)	0.47 (0.21)
Experiment 2	High FAS	0.12 (0.05)	0.06 (0.02)	0.39 (0.30)
	Low FAS	0.13 (0.08)	0.01 (0.01)	0.39 (0.27)
Experiment 3	High ID	0.15 (0.03)	0.02 (0.02)	0.87 (0.06)
	Low ID	0.13 (0.07)	0.02 (0.01)	0.05 (0.03)

Note: Standard deviations are shown in parentheses.

Table 2.
Sixteen DRM Lists Used in Experiment 1 and Their Backward Associative Strength (BAS), Forward Associative Strength (FAS), And Identifiability (ID) Values.

CRITICAL LURE: associated words (approximated English translation)	**BAS**	**FAS**	**ID**
Low-BAS lists			
JUEGO: balón, deportes, béisbol, baloncesto, bola, tenis (GAME: ball, sports, baseball, basketball, pellet, tennis)	.033	.008	.171
RIQUEZA: poderoso, palacio, aristocracia, lujo, nobleza, poder (WEALTH, powerful, palace, aristocracy, luxury, nobility, power)	.042	.005	.257
NOCHE: cama, pesadilla, camisón, descansar, soñar, cansancio (NIGHT: bed, nightmare, nightdress, to rest, to dream, tiredness)	.044	.001	.371
FELICIDAD: carcajada, humor, sonrisa, gracia, diversión, simpatía (HAPPINESS: laugh, humor, smile, jocularity, fun, sympathy)	.045	.008	.522
VISTA: óptica, ojo, lentillas, prismáticos, lupas, visión (SIGHT: optics, eye, contact lenses, binoculars, magnifiers, vision)	.050	.033	.525
COLONIA: jazmín, perfume, aroma, fragancia, esencia, violeta (COLOGNE: jasmine, perfume, aroma, fragrance, essence, violet)	.056	.037	.413
CIELO: globo, cometa, avión, helicóptero, pájaro, águila (SKY: balloon, kite, plane, helicopter, bird, eagle)	.056	.000	.650
INVIERNO: estufa, abrigo, manta, bufanda, escalofrío, gorro (WINTER: stove, coat, blanket, scarf, chill, bonnet)	.062	.002	.825
High BAS lists			
PUEBLO: rural, urbe, villa, urbana, municipio, habitante (VILLAGE: rural, metropolis, town, urban, municipality, inhabitant)	.198	.006	.425
PISTOLA: balas, disparo, revólver, rifle, fusil, metralleta (PISTOL: bullets, shot, revolver, rifle, handgun, machine gun)	.199	.013	.152
CASA: vivienda, portal, fachada, arquitecto, ático, viga (HOME: dwelling, doorway, facade, architect, attic, beam)	.261	.002	.609
CURA: clérigo, sotana, sacerdote, fraile, monasterio, monja (CLERGYMAN: cleric, cassock, priest, friar, monastery, nun)	.275	.023	.057
PERRO: maullido, mascota, maullar, pulgas, rabo, veterinaria (DOG: meow, pet, to meow, fleas, tail, veterinary)	.289	.002	.217
MAR: olas, orilla, bahía, costa, nadar, puerto (SEA: waves, shore, bay, coast, to swim, port)	.319	.014	.688
DINERO: monedero, cobrar, salario, empleo, jornal, paga (MONEY: purse, to charge, salary, employment, day's pay, pay)	.324	.003	.800
CÁRCEL: rejas, prisionero, celda, reo, presidio, reclusión (JAIL: bars, prisoner, cell, offender, penitentiary, imprisonment)	.365	.032	.938

Data Analysis

The analyses were performed using JASP Team (2020). Repeated measures analyses of variance (ANOVAs) and paired samples *t*-test were performed. Across all frequentist analyses, the alpha level was set at .05, effect sizes are reported with Cohen's d and omega squared (ω^2), and the 95% confidence intervals (CI) for the effect sizes are detailed. Where appropriate, in the repeated measures ANOVAs, degrees of freedom were corrected using the Greenhouse-Geisser estimator. Furthermore, to overcome the limitations of the null hypothesis significance testing, Bayesian paired samples *t*-test analyses were also conducted.

Results

The mean percentages of true and false recognition as a function of BAS (high vs. low) are presented in Table 3. Additionally, the sensitivity index d prime (d'), derived from the signal-detection theory (Hautus et al., 2022), was included for the list items and the critical lures.

False Memory Effect

To test for the presence of false recognition, a one-way repeated measures ANOVA was conducted by comparing the percentage of studied words, critical lures, unrelated distractors, and unrelated-critical distractors that were judged "old" on the recognition memory test. This analysis yielded a significant difference among the type of words, $F(2.16, 174.75) = 463.62$, $p < .001$, $\omega^2 = .79$, and Bonferroni post-hoc analyses showed that the percentage of correctly recognized studied words ($M = 75.18$, $SD = 12.51$) was greater than false alarms to critical lures ($M = 34.27$, $SD = 20.73$), unrelated distractors ($M = 6.30$, $SD = 7.18$), and unrelated-critical distractors ($M = 9.55$, $SD = 13.62$), all $ps < .001$, all Cohen's d above 1.1. Moreover, false alarms to critical lures were higher than false alarms to both unrelated distractors and unrelated-critical distractors, both $ps < .001$, confirming that our DRM lists produced the typical false memory effect. Finally, there were no significant differences between false alarms to unrelated distractors and unrelated-critical distractors, $p = .059$, 95% CI for mean difference [-0.07, 6.58].

Table 3.
Mean Percentage (SD) of True and False Recognition in Experiment 1 (BAS), Experiment 2 (FAS), And Experiment 3 (ID).

	Experiment 1		Experiment 2		Experiment 3	
	High BAS	Low BAS	High FAS	Low FAS	High ID	Low ID
True recognition	75.61 (14.11)	74.76 (15.03)	74.83 (14.09)	73.52 (16.59)	76.49 (13.98)	76.95 (13.82)
List-item *d'*	2.26 (0.67)	2.20 (0.60)	2.27 (0.64)	2.15 (0.65)	2.16 (0.72)	2.28 (0.64)
False recognition	39.51 (25.53)	29.02 (23.13)	45.68 (24.44)	15.68 (18.31)	31.03 (22.36)	39.31 (20.56)
Critical-lure *d'*	0.46 (0.70)	0.30 (0.61)	0.74 (0.62)	-0.05 (0.48)	0.18 (0.70)	0.54 (0.65)

The Influence of Backward Associative Strength (BAS) on True and False Recognition

A 2 (type of word: studied, critical) x 2 (BAS: high, low) repeated measures ANOVA was conducted to examine the effect of BAS on true recognition (hits to studied words) and false recognition (false alarms to critical lures) (Beato & Arndt, 2014). This analysis of variance revealed a significant main effect of type of word, $F(1, 81) = 245.89$, $p < .001$, $\omega^2 = .59$, a significant main effect of BAS, $F(1, 81) = 9.49$, $p = .003$, $\omega^2 = .03$, and a significant Type of Word x BAS interaction, $F(1, 81) = 11.82$, $p = .001$, $\omega^2 = .03$. We computed two comparisons and applied Bonferroni correction, setting the new alpha at .025. High-BAS lists produced higher false recognition than low-BAS lists (39.51 vs. 29.02, respectively), $t(81) = 3.71$, $p < .001$, Cohen's $d = 0.41$, 95% CI [0.18, 0.63]. No differences were found in true recognition rates produced with high-BAS and low-BAS lists, $t(81) = 0.52$, $p = .61$, Cohen's $d = 0.06$, 95% CI [-0.16, 0.27]. As expected, the backward associative strength manipulation influenced false recognition but did not influence true recognition.

The null hypothesis significance testing has limitations (Dienes, 2011) that can be addressed by running Bayesian analyses. Two Bayesian paired samples t-test analyses allowed us to examine two hypotheses and provide evidence in favor of one of them: H0 = no differences between the means, H1 = differences between the means. Regarding false recognition, the Bayes factor indicated that the data is 58.60 times more likely under the H1 than the H0. In other words, there was very strong evidence for differences between high- and low-BAS lists ($BF^{10} = 58.60$) in false recognition. Concerning true recognition, there was moderate to strong evidence that high-BAS and low-BAS lists do not differ ($BF^{10} = 0.14$). Specifically, the data is 7.22 times more likely under the H0 than the H1.

Finally, we calculated the sensitivity index *d'*, a standardized difference between the proportion of hits and false alarms that provides a measure of discriminability that is unaffected by response biases (MacMillan & Creelman 1991). In the DRM paradigm context, *d'* has been commonly understood as an estimate of the amount of information encoded at study about studied items and critical lures (Bodner et al., 2017; Gunter et al., 2007; Huff et al., 2015, 2020; Huff & Bodner, 2013; Namias et al., 2022). List-item *d'* was computed by taking the difference between the z-score for the hit rate for studied words minus the z-score for the false alarms to unrelated distractors. Critical-lure *d'* was calculated by subtracting the z-score for the proportion of "yes" responses to critical lures from the z-scores for the false alarms to unrelated-critical distractors. Perfect accuracy was adjusted using MacMillan and Creelman's (1991) correction.

Paired-sample *t*-tests indicated that, during the study phase, the amount of information encoded by participants did not differ between the studied items of the high-BAS and low-BAS lists (see Table 3), $t(81) = 0.70$, $p = .485$, Cohen's $d = 0.08$, 95% CI [-0.14, 0.29]. In contrast, the amount of information encoded about the critical lures differed between BAS conditions as more information was encoded about the critical lures of the high-BAS than low-BAS lists, $t(81) = 2.01$, $p = .048$, Cohen's $d = 0.22$, 95% CI [0.01, 0.44].

Together, these findings are consistent with previous literature that has shown that high-BAS lists produced higher false recognition than low-BAS lists (e.g., Arndt & Gould, 2006). Moreover, this experiment extends those results to show for the first time that BAS increases false recognition when it is not confounded with FAS and ID.

Experiment 2

In Experiment 2, we compared true and false recognition rates obtained in high- and low-FAS lists. Unlike previous research, both BAS and ID levels were strictly controlled (see Table 1), so the FAS effect on false memory is disentangled from these other two influential variables. We had no a priori hypothesis about FAS manipulation, as previous research has shown mixed results.

Method

Participants

Seventy-five participants are required to detect a medium size effect (d = .50) in the interaction of a 2 x 2 repeated measures ANOVA (Brysbaert, 2019, p.25). In this experiment, 88 undergraduate native Spanish speakers participated voluntarily in exchange for course credit. Their ages ranged from 19 to 28 years ($M = 19.70$, $SD = 1.44$), and 89.77% were women. The Bioethics Committee at the University of Salamanca approved the study.

Instruments

Sixteen DRM lists composed of a critical lure with forward associative strength (FAS) to six associates were selected from a previous normative study (Beato & Cadavid, 2016). Eight high-FAS lists ($M = .06$, $SD = .02$) and eight low-FAS lists ($M = .01$, $SD = .01$) were employed (see Table 4).

The forward associative strength of the high-FAS and low-FAS lists differed significantly, $t(7.02) = 7.87$, $p < .001$, Cohen's $d = 3.94$, 95% CI [1.68, 6.16]. The high- and low-FAS lists did not show significant differences in their BAS values, $t(14) = -0.15$, $p = .882$, Cohen's $d = -0.08$, 95% CI [-1.05, 0.91], nor in their ID values, $t(14) = 0.01$, $p = .998$, Cohen's $d = 0.001$, 95% CI [-0.98, 0.98]. That is, neither BAS nor ID differed significantly between high- and low-FAS lists (see Table 1). Ten lists were randomly assigned to serve as studied. The remaining six lists served as distractors, and the recognition memory test was similar to that used in Experiment 1.

Table 4.
Sixteen DRM Lists Used in Experiment 2 and Their Forward Associative Strength (FAS), Backward Associative Strength (BAS), And Identifiability (ID) Values.

CRITICAL LURE: associated words (approximated English translation)	**FAS**	**BAS**	**ID**
Low-FAS lists			
DIVERSIÓN: guateque, verbena, festival, baile, concierto, discoteca (FUN: bash, open air dance, festival, dance, concert, disco)	.003	.048	.314
PERRO: maullido, mascota, maullar, pulgas, rabo, veterinaria (DOG: meow, pet, to meow, fleas, tail, veterinary)	.002	.289	.217
TRABAJO: monedero, cobrar, salario, empleo, jornal, paga (WORK: purse, to charge, salary, employment, day's pay, pay)	.002	.122	.600
PELÍCULA: escena, interpretación, escenario, actriz, intérprete, actuar (FILM: scene, interpretation, stage, actress, interpreter, to act)	.002	.068	.283
CASA: rural, urbe, villa, urbana, municipio, habitante (HOME: rural, metropolis, town, urban, municipality, inhabitant)	.001	.057	.125
FLOR: raíz, tallo, semilla, laurel, brote, hojas (FLOWER: root, stem, seed, laurel, shoot, leaves)	.001	.119	.125
GUERRA: metralleta, balas, munición, fusil, rifle, disparo (WAR: machine gun, bullets, ammunition, handgun, rifle, shot)	.001	.146	.575
AGUA: cauce, pez, orilla, lago, barca, bahía (WATER: riverbed, fish, shore, lake, boat, bay)	.001	.154	.886
High FAS lists			
DORMIR: mesilla, descansar, sueño, camisón, descanso, soñar (TO SLEEP: bedside table, to rest, dream, nightdress, rest, to dream)	.088	.220	.825
CIGARRO: cenicero, pipa, humo, mechero, puro, pulmones (CIGARETTE: ashtray, pipe, smoke, lighter, cigar, lungs)	.080	.132	.250
ENSALADA: lechuga, alcachofa, pimiento, tomate, coliflor, rábano (SALAD: lettuce, artichoke, pepper, tomato, cauliflower, radish)	.072	.115	.174
VOLAR: globo, cometa, avión, helicóptero, pájaro, águila (TO FLY: balloon, kite, plane, helicopter, bird, eagle)	.064	.167	.800
MONJE: clérigo, sotana, sacerdote, fraile, monasterio, monja (MONK: cleric, cassock, priest, friar, monastery, nun)	.055	.102	.000
MATRIMONIO: nupcial, novios, enlace, compromiso, pareja, casar (MARRIAGE: bridal, newlyweds, bond, commitment, couple, to marry)	.037	.101	.514
HORROR: pavor, temor, pánico, espanto, susto, pesadilla (HORROR: dread, awe, panic, fright, scare, nightmare)	.037	.070	.152
COLONIA: jazmín, perfume, aroma, fragancia, esencia, violeta (COLOGNE: jasmine, perfume, aroma, fragrance, essence, violet)	.037	.056	.413

Procedure

The procedure was identical to the one used in Experiment 1.

Data Analysis

The analyses were performed in a similar way to Experiment 1.

Results

The mean percentages of true and false recognition and sensitivity indexes as a function of FAS (high vs. low) are presented in Table 3.

False Memory Effect

A one-way repeated measures ANOVA performed on the percentage of studied words, critical lures, unrelated distractors, and unrelated-critical distractors that were judged "old" on the recognition memory test revealed a significant difference among the types of words, $F(2.58, 223.99) = 727.75$, $p < .001$, $\omega^2 = .83$. Bonferroni post-hoc analyses showed that true recognition (M = 74.18, SD = 12.84) was higher than false alarms to critical lures (M = 30.68, SD = 17.01), unrelated distractors (M = 6.01, SD = 7.44), and unrelated-critical distractors (M = 6.44, SD = 11.14), $p < .001$ and $d > 1.45$ for all comparisons. This analysis also revealed that false alarms to critical lures were greater than both unrelated distractors and unrelated-critical distractors, both $ps < .001$, demonstrating that our DRM lists produced false memory effect. Finally, there were no significant differences between false alarms to unrelated distractors and unrelated-critical distractors, $p = 1.00$.

The Influence of Forward Associative Strength (FAS) on True and False Recognition

In order to evaluate the effect of FAS on true and false recognition, a 2 (type of word: studied, critical) x 2 (FAS: high, low) repeated measures ANOVA was performed on the percentage of "old" responses given to each type of word. This ANOVA yielded a significant main effect of type of word, $F(1, 87) = 540.54$, $p < .001$, $\omega^2 = .68$, and a significant main effect of FAS, $F(1, 87) = 81.19$, $p < .001$, $\omega^2 = .22$. Finally, the interaction Type of Word x FAS was also statistically significant, $F(1, 87) = 77.79$, $p < .001$,

ω^2 = .20. Just as in Experiment 1, we computed two comparisons and applied Bonferroni correction, setting the new alpha at .025. There were no significant differences in true recognition (hits to studied words) produced by high-FAS and low-FAS lists (74.83 vs. 73.52, respectively), $t(87) = 0.72$, $p = .473$, Cohen's $d = 0.08$, 95% CI [-0.13, 0.29]. On the contrary, false recognition (false alarms to critical lures) elicited by high-FAS and low-FAS lists (45.68 vs. 15.68, respectively) did significantly differ, $t(87) = 10.58$, $p < .001$, Cohen's $d = 1.13$, 95% CI [0.86, 1.39].

Again, Bayesian paired samples *t*-test analyses were conducted. With respect to true recognition, the Bayes factor (BF^{10} = 0.15) indicated moderate to strong support in favor of the H0 (i.e., no differences between high-FAS and low-FAS lists). Regarding false recognition, the Bayes factor (BF^{10} = 2.16 * 1014) points at extreme evidence in support of H1 (i.e., existence of differences in false recognition between high-FAS and low-FAS lists).

Regarding the sensitivity index (*d'*), paired-sample *t*-tests showed that the amount of information encoded by participants about the studied items did not differ between the high- and low-FAS lists (see Table 3), $t(87) = 0.63$, $p = .528$, Cohen's $d = 0.07$, 95% CI [-0.14, 0.28]. However, as in Experiment 1 with BAS lists, participants encoded more information about the critical lures of the high-FAS than low-FAS lists, $t(87) = 9.98$, $p < .001$, Cohen's d = 1.06, 95% CI [0.80, 1.32].

These results clearly show that FAS does influence false memory formation within the DRM paradigm and help elucidate a question that had accumulated mixed results. As stated earlier, this is the very first time that the FAS effect is simultaneously torn apart from other associative (i.e., BAS) and strategic (i.e., ID) forces, thus being able to observe its effect on false memories.

Experiment 3

In Experiment 3, we explored differences in false memory triggered by high-ID and low-ID lists. Previous research had explored this difference, but this is the first time in the literature that materials are controlled in their forward and backward associative forces (see Table 1). According to past research, we expected lower false recognition in high- than low-ID lists.

Method

Participants

In order to detect a medium size effect ($d = .50$) in the interaction of a 2 x 2 repeated measures ANOVA, 75 participants are needed (Brysbaert, 2019, p.25). In Experiment 3, 85 students participated voluntarily in this study in exchange for course credit. They were native Spanish speakers (83.53% women), and their ages ranged from 19 to 27 years ($M = 19.82$, $SD = 1.48$). The Bioethics Committee at the University of Salamanca approved the study.

Instruments

A total of 16 lists from Beato & Cadavid (2016) were employed in this experiment (see Table 5). Eight DRM lists were selected to have high-ID values ($M = .87$, $SD = .06$) and other eight lists were chosen to have low-ID values ($M = .05$, $SD = .03$), $t(14) = 33.11$, $p < .001$, Cohen's $d = 16.55$, 95% CI [10.41, 22.47]. High-ID and low-ID lists did not show significant differences regarding their BAS values, $t(9.00) = 0.85$, $p = .420$, Cohen's $d = 0.42$, 95% CI [-0.59, 1.41], nor their FAS values, $t(14) = -0.18$, $p = .859$, Cohen's $d = -0.09$. 95% CI [-1.07, 0.89] (see Table 1). The assignment of the lists to be studied and distractors was counterbalanced across participants. The recognition memory test was similar to that used in Experiments 1 and 2.

Procedure

The procedure was identical to the one used in Experiments 1 and 2.

Data Analysis

The analyses were performed in a similar way to Experiments 1 and 2.

Results

The mean percentages of true and false recognition and sensitivity indexes as a function of ID (high vs. low) are presented in Table 3.

False Memory Effect

A one-way repeated measures ANOVA comparing the percentage of studied words, critical lures, unrelated distractors, and unrelated-critical distractors that were judged "old" on the recognition memory test showed a significant difference among the types of words, $F(2.53, 217.64) = 546.57$, $p < .001$, $\omega^2 = .80$. Bonferroni post-hoc analyses revealed that true recognition (M = 76.72, SD = 11.82) was higher than false alarms to critical lures (M = 35.17, SD = 16.77), unrelated distractors ($M = 8.10$, $SD = 9.32$), and unrelated-critical distractors ($M = 12.26$, $SD = 15.56$), all *ps* < .001 and $d > 2.19$. Moreover, false alarms to critical lures were higher than unrelated distractors and unrelated-critical distractors, both *ps* < .001 and $d > 1.10$, confirming that the DRM lists used in this experiment produced robust levels of false recognition. There were no significant differences between false alarms to unrelated distractors and unrelated-critical distractors, $p = .064$, 95% CI for mean difference [-0.14, 8.47].

The Influence of Theme Identifiability (ID) on True and False Recognition

To evaluate true and false recognition as a function of ID, a 2 (type of word: studied, critical) x 2 (ID: high, low) repeated measures ANOVA was conducted comparing the percentage of "old" responses given to each type of word. This analysis revealed a significant main effect of type of word, $F(1, 86) = 416.84$, $p < .001$, $\omega^2 = .67$, a significant main effect of ID, $F(1, 86) = 6.80$, $p = .011$, $\omega^2 = .02$, and a significant Type of Word x ID interaction, $F(1, 86) = 5.95$, $p = .017$, $\omega^2 = .02$. Following the ANOVA, two comparisons were run to better understand the interaction effect (new alpha set at .025). There were no differences in true recognition between high-ID and low-ID lists (76.49 vs. 76.95, respectively), $t(86) = 0.29$, $p = .77$, Cohen's $d = 0.03$, 95% CI [-0.18, 0.24]. Instead, high- and low-ID lists (39.31 vs. 31.03, respectively) did show significant differences in false recognition, $t(86) = 2.87$, $p = .005$, Cohen's $d = 0.31$, 95% CI [0.09, 0.52].

Table 5.
Sixteen DRM Lists Used in Experiment 3 and Their Identifiability (ID), Backward Associative Strength (BAS), And Forward Associative Strength (FAS) Values.

CRITICAL LURE: associated words (approximated English translation)	**ID**	**BAS**	**FAS**
Low ID lists			
CATARRO: contagio, virus, constipado, tos, resfriado, estornudo (CATARRH: contagion, virus, to have a cold, cough, cold, sneeze)	.000	.078	.048
FRESA: batido, sabor, caramelo, pastel, mermelada, tarta (STRAWBERRY: milkshake, flavor, candy, pie, jam, cake)	.025	.168	.014
CURA: clérigo, sotana, sacerdote, fraile, monasterio, monja (CLERGYMAN: cleric, cassock, priest, friar, monastery, nun)	.057	.275	.023
MAR: cauce, pez, orilla, lago, barca, bahía (SEA: riverbed, fish, shore, lake, boat, bay)	.057	.173	.003
SONRISA: júbilo, risa, simpatía, optimismo, reír, carcajada (SMILE: jubilation, laughter, sympathy, optimism, to laugh, laugh)	.057	.064	.021
PRESO: rejas, prisionero, celda, reo, presidio, reclusión (INMATE: bars, prisoner, cell, offender, penitentiary, imprisonment)	.063	.092	.015
CALOR: bufanda, manta, invierno, jersey, escalofrío, gabardine (HEAT: scarf, blanket, winter, jersey, chill, raincoat)	.063	.086	.003
BEBIDA: vodka, juerga, ron, licor, borracho, borrachera (DRINK: vodka, spree, rum, liqueur, drunk, drunkenness)	.094	.113	.011
High ID lists			
VOLAR: globo, cometa, avión, helicóptero, pájaro, águila (TO FLY: balloon, kite, plane, helicopter, bird, eagle)	.800	.167	.064
ANIMAL: felino, fiereza, zarpa, veterinaria, garra, hiena (ANIMAL: feline, ferocity, paw, veterinary, claw, hyena)	.813	.105	.003
PLANTA: raíz, tallo, semilla, laurel, brote, hojas (PLANT: root, stem, seed, laurel, shoot, leaves)	.825	.157	.003
VERDURA: alcachofa, coliflor, rábano, acelgas, pimiento, apio (VEGETABLE: artichoke, cauliflower, radish, Swiss chard, pepper, celery)	.857	.142	.008
TEATRO: escena, estreno, escenario, trama, actor, ficción (THEATRE: scene, premiere, stage, plot, actor, fiction)	.875	.178	.013
ARMA: revólver, bala, rifle, fusil, metralleta, escopeta (WEAPON: revolver, bullet, rifle, handgun, machine gun, shotgun)	.875	.144	.008
DORMIR: almohada, lecho, sueño, sábana, sofá, cansancio (TO SLEEP: pillow, resting place, dream, sheet, sofa, tiredness)	.906	.143	.025
FIESTA: verbena, guateque, tocadiscos, disco, discoteca, concierto (PARTY: open air dance, bash, record player, record, disco, concert)	1.000	.194	.001

As in previous experiments, we conducted Bayesian analyses. Regarding true recognition, the Bayes factor (BF^{10} = 0.12) indicated moderate to strong evidence for the H0: no differences between high-ID and low-ID lists. With respect to false recognition, the Bayes factor (BF^{10} = 5.44) indicated moderate evidence for the H1: the existence of differences in the false memory effect produced by high-ID and low-ID lists.

Lastly, we analyzed the *d'* values. Regarding list-item *d'*, a paired-sample *t*-test demonstrated that, as expected, the amount of information encoded by participants about the studied items did not differ between the high- and low-ID lists (see Table 3), $t(86) = -1.38$, $p = .170$, Cohen's $d = -0.15$, 95% CI [-0.36, 0.06]. However, we found that critical-lure d' was significantly lower in high-ID than in low-ID lists, $t(86) = -3.73$, $p < .001$, Cohen's $d = -0.40$, 95% CI [-0.62, -0.18]. This lower discriminability in the high-ID lists would be supporting the idea that the high theme identifiability facilitates error-editing processes, leading participants to reject the critical lures in the memory test.

These results showed that the level of ID of the critical lure influences false memory. Specifically, ID only affected false recognition but did not influence true recognition. For the first time, we have evidence that strategic processes such as identifying the critical lure do influence false memory, even in the absence of mediation of associative forces. This result provides evidence in support of the interplay between two opposing processes in false memory formation: error-inflating and error-editing processes.

Discussion

The aim of this research was to unravel the puzzling variability of false memory rates obtained with the Deese/Roediger-McDermott (DRM) paradigm. The two main theories in the DRM paradigm (i.e., activation-monitoring framework and fuzzy-trace theory) postulate that the interplay of two opposing processes (i.e., error-inflating and error-editing processes) could help explain this variability. In three experiments, we examined the effect on false memory of (a) two variables associated with error-inflating processes (i.e., backward and forward associative strength, BAS and FAS, respectively) and (b) one variable related to error-editing mechanisms (i.e., theme identifiability, ID). Previous research has not considered the potential confounding effects of these opposing forces when trying to explain the variability in false memory raised with the DRM paradigm, thereby not providing a clear picture of the role of the most frequently cited explanatory variables in the field. Here, for the first time in literature, the effects of BAS, FAS, and ID were examined independently. Hence, this research aimed to disentangle the role of each of these variables on the false memory effect. In our three experiments, the materials were strictly selected. Particularly, three sets of DRM lists were created so (1) BAS was manipulated while FAS and ID were controlled (Experiment 1), (2) FAS was manipulated while BAS and ID were controlled (Experiment 2), and (3) ID was manipulated while BAS and FAS were controlled (Experiment 3).

Previous literature has already manipulated these variables while controlling for just one of the other two. For example, on the one hand, some studies have independently manipulated error-inflating processes like BAS and FAS in factorial designs. They have reported that both variables affected the magnitude of the false memory effect with higher false recognition rates for high- than low-BAS and -FAS lists (e.g., Brainerd & Wright, 2005; Cadavid et al., 2012; Howe et al., 2009), but none of these studies have taken into account the possible intervention of error-editing processes on false memories. On the other hand, among the studies that have examined the effect of the error-editing processes on false memory using ID, to our knowledge, only one has torn apart the effect of ID from BAS (Carneiro & Fernandez, 2013), but FAS values were not considered. Thus, as far as we know, this is the first time in the literature that error-inflating and error-editing processes, studied through BAS, FAS, and ID, are examined while simultaneously controlling the other two. Although it was not an easy experimental control to execute, testing these materials in three different experiments allowed us to get a clearer picture of the role that these variables play on promoting error-inflating and error-editing processes in false memory.

First, two variables related to error-inflating processes were tested in two experiments: BAS and FAS. Regarding BAS, as expected, the results of Experiment 1 replicated the findings of previous research showing higher false recognition in high-BAS lists than in low-BAS lists (e.g., Beato & Arndt, 2017; Knott et al., 2012; McEvoy et al., 1999). Furthermore, we extended this conclusion regarding the effect of BAS on false memory when BAS was not confounded with FAS nor ID. Focusing now on FAS, its effect on previous literature was not straightforward as mixed results has been shown (e.g., Beato & Arndt, 2021a; Howe et al., 2009; Roediger et al., 2001). The data obtained in our Experiment 2 revealed that, when BAS and ID were kept under control, high-FAS lists produced higher false recognition than low-FAS lists. Together, the results of BAS and FAS experiments show that a richer and denser network of pre-existing associations between the studied items and the critical lures raises the likeability of committing false memory. This finding has great implications for research that uses DRM tasks to explore other cognitive domains, such as second-language acquisition or cognitive development. The study of the structure of associative networks could shed light on the formation of associations between words during first-language or second-language learning.

Second, to examine the relevance of error-editing processes without them being confounded with error-inflating processes, ID values were manipulated in Experiment 3 using DRM lists that did not differ in terms of BAS and FAS values. Previous research that has analyzed the effect of ID on false memory has found that high-ID lists produced lower false memory than low-ID lists due to the engagement of error-editing processes (Carneiro et al., 2009, 2012; Neuschatz et al., 2003). However, virtually no previous work has simultaneously torn apart the effect of ID from the effect of BAS and FAS. In Experiment 3 we exerted strict controls over the materials used and replicated the main finding of the effect of ID on false memory in the DRM paradigm. Specifically, ID affected false recognition, showing a lower false recognition rate for high-ID than low-ID lists. Checking that some variables can promote error-editing mechanisms might encourage researchers to keep looking for strategies to avoid false memories. These more strategic and cognitively sophisticated processes might be trained to engage deliberately. Therefore, exploring how error-editing processes by themselves work seems critical to several fields of research, such as legal or clinical psychology.

In summary, we overcame the lack of experimental control of previous studies in which BAS, FAS, and ID were confounded. Not having “pure” variables is problematic because associative strength and theme identifiability produce opposite effects on false memories. Therefore, if we do not control for BAS and FAS when studying ID, two forces in opposite directions may nullify the effect we want to examine. In this research, we used strictly controlled materials that allowed us to provide evidence on the relevance of error-inflating and error-editing processes alone on false memory. Particularly, our data suggest that while high associative strength, both backward and forward, increases the likelihood of committing false memories, high identifiability of the theme of the lists (i.e., critical lure) tends to reduce the chances of producing them. These results go in line with previous research, but we have also extended this conclusion to an experimental scenario in which each studied variable is not confounded with one another.

In conclusion, the results of these three experiments align with the dual-process theories as we have proven how BAS and FAS separately increase false memory (i.e., error-inflating processes), whereas theme identifiability decreases it (i.e., error-editing processes), even when is not confounded with the main associative forces. This outcome has relevant theoretical implications as we are considering, within the same experimental design, variables that promote two opposite processes in the production of false memories. Hence, our research contributes to the understanding that there are several sources of variability within the DRM paradigm research, and it opens the door to new perspectives in this field. For example, the associative nature of lists may be advantageous for studying phenomena such as second-language learning. Also, based on the signal-detection theory, it would be interesting to explore how individual differences in terms of sensitivity or response bias could be affecting the false recognition in the different type of DRM lists. Finally, exploring to what extent deliberate strategies could help people to avoid false memories seems to be a challenging and fruitful line of research in forensic psychology.

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