



# The role of individual differences in face recognition and mental imagery on face-memory specificity and inhibition<sup>☆</sup>

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## ABSTRACT

Our previous research found that long-term facial memory specificity depends on detailed memory for individual faces and unintentional inhibition of closely related faces. The current study investigated whether individual differences in facial recognition and mental imagery ability influenced this inhibitory processing in facial memory specificity. During the study phase, participants viewed neutral Caucasian faces. During the test phase, participants were presented with old faces, related faces (created by morphing faces along an old–new continuum in steps of 20 %), and new faces and made “old”–“new” recognition judgments. The Vividness of Visual Imagery Questionnaire (VVIQ) and the Cambridge Face Memory Test (CFMT) were used to assess mental imagery and face recognition ability, respectively. We found evidence for detailed memory retrieval (i.e., the ability to discriminate between old and highly related face morphs) as the “old” response rate for old faces was significantly greater than that of 20 % morphs. Furthermore, there was evidence for memory inhibition as the “old” response rate for 20 % morphs was significantly lower than that of 40 % morphs (replicating our previous findings). CFMT scores were significantly correlated with detailed memory retrieval but were not associated with inhibition. VVIQ scores were not associated with either detailed memory retrieval or inhibition. These results support the role of inhibition in memory for faces and further suggest that these processes are unintentional.

Accurately retrieving specific memories is thought to rely on inhibition of interfering or related information (Anderson et al., 1994; Healey et al., 2014; Ngo & Hasher, 2017). This has previously been studied using tasks such as the retrieval-practice paradigm (Anderson et al., 1994). Findings from research using this paradigm suggest that inhibition occurs unintentionally (i.e., involuntarily) during memory selection to help recall the appropriate memory from competing ones (for reviews, see Anderson & Hanslmayr, 2014; Anderson & Hulbert, 2021; Levy & Anderson, 2002). In the encoding phase of this paradigm, participants study category-exemplar pairs from different semantic categories (e.g., for the categories “color” and “metal”, category-exemplar pairs could be: “color-blue”, “color-red” or “metal-copper”). In the subsequent intermediate phase, participants practice retrieving exemplars from some of the categories (e.g., practicing “color-blue”, but not “color-red” for the color category, and do not practice any of the exemplars from the metal category, which is used as a baseline). This is followed by a test phase in which participants retrieve all category-

exemplar pairs that were initially studied. As expected, practiced items (e.g., “color-blue”) are better remembered than unpracticed items (e.g., “color-red”). However, unpracticed items are remembered less than baseline items (e.g., “color-red” is remembered less than “metal-copper”). This finding is thought to reflect an unintentional inhibitory mechanism that suppresses similar items in memory (as the items that were not practiced were semantically related to the items which were practiced). This pattern of results has been referred to as “retrieval-induced forgetting” (RIF; Anderson et al., 1994). While retrieval-induced forgetting has largely been studied using verbal stimuli, it has also been shown to occur with visual stimuli (Maxcey & Woodman, 2014; Rugo et al., 2017; Scotti et al., 2020; Wimber et al., 2015). These results suggest that inhibition can suppress related or competing information in memory, which enables us to more accurately retrieve previously experienced information.

Furthermore, the degree of similarity or competition between exemplars within individual categories can also impact RIF (for a review,

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see Marsh & Anderson, 2022). For example, one study modified the retrieval-practice paradigm so that during the encoding phase participants were exposed to unrelated exemplars or related exemplars (Anderson et al., 2000). They found that exemplars with high similarity increased retrieval impairment (i.e., there was more inhibition, which led to more forgetting of the highly similar exemplars), whereas exemplars with low similarity had the opposite effect (i.e., they were remembered more). Additionally, a meta-analysis investigating the role of taxonomic frequency in verbal stimuli used in the retrieval-practice paradigm found more RIF for stronger exemplars than for weaker exemplars (Murayama et al., 2014). These findings show that inhibition can be flexibly directed at stimuli of varying similarity to help discriminate between related and target memories.

While these studies demonstrate that similar competitors are inhibited during memory retrieval, they primarily used semantic stimuli, which are hard to systematically adapt to create varying levels of relatedness. Recently, we investigated inhibition in long-term memory specificity using a novel distorted-item paradigm (Jeye et al., 2020) using visual stimuli (i.e., faces). Furthermore, an additional benefit of this distorted-item paradigm is that it only consists of a study and test phase, which more directly mimics the real-world environment (unlike the retrieval-practice paradigm which also has an intermediate practice phase). During the study phase of the distorted-item paradigm, participants were asked to remember male and female Caucasian faces, and then were given an old–new recognition memory test in which they saw a second set of faces. This second set of faces consisted of old, related (i.e., morphs of old faces), and new faces. We first found that memory representations were very specific as the “old” response rate to old faces was significantly greater than highly similar morphs. We also found that the “old” response rate for highly similar morphed faces was significantly lower than more distantly related morphed faces. This reflects the unintentional inhibition of closely related faces, similar to what is observed during the retrieval-practice paradigm, with retrieval-induced forgetting.

Taken together, this research along with the research on RIF demonstrates that long-term memory depends on both accurately retrieving detailed representations and, also, unintentionally inhibiting highly similar (i.e., competing) information. In the present study, we examined how individual differences in cognitive processes related to intentional (i.e., voluntary) visualization (such as mental imagery and facial recognition) influence these processes in our distorted-item paradigm. For example, individual differences in how details are visualized might influence how well participants accurately remember old faces. That is, individuals who are better able to intentionally form detailed images of specific faces might be better at distinguishing old faces from highly related competitors. Similarly, inhibition may depend on how well an individual can call to mind details during the retrieval process, which would predict a relationship between visualization and inhibitory processing. Alternatively, if inhibition during memory retrieval is completely unintentional (i.e., automatic or involuntary), we would expect no relationship between how well an individual can intentionally visualize details and their performance in the distorted-item paradigm.

To investigate these questions, we first evaluated individual’s mental imagery ability. Mental imagery is the ability to form voluntary visual images and is typically assessed using the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973). The VVIQ asks participants to create a mental image for 16 different items and then rate the vividness of the imagery on a five-point scale. Individuals who score low on the VVIQ are thought to have aphantasia (i.e., the inability to form voluntary mental imagery), and it has been shown that aphantasics can have deficits in memory, including working memory as well as object memory (Bainbridge et al., 2021b; Brewer & Pani, 1996; Jacobs et al., 2018). For example, in a recent study by Bainbridge et al. (2021b), participants with aphantasia (as measured via the VVIQ) studied real-world scene images (e.g., a bedroom or a kitchen) and then drew them from memory. It was found that, although spatial memory was preserved, object

memory was significantly impaired in individuals with aphantasia in comparison to controls (i.e., individuals without aphantasia). There is also empirical support connecting mental imagery and autobiographical memory (a specific type of long-term memory that is associated with memory for one’s personal lifetime events; Butler et al., 2016; Greenberg & Knowlton, 2014; Rubin, 2006; Vannucci et al., 2016; Williams et al., 1999). For instance, enhanced autobiographical memory is associated with higher levels of mental imagery ability (Vannucci et al., 2016) and high mental imagery is associated with facilitated access (i.e., quicker reaction time) to specific memories of autobiographical events (Williams et al., 1999). Furthermore, a meta-analysis by Svoboda et al., (2006) found neural evidence for this relationship, where the same regions involved in visual mental imagery and visuospatial processing, such as occipital regions, were also active during autobiographical memory retrieval. These results indicate that there is a relationship between mental imagery ability and memory.

Of particular relevance to the current study, mental imagery has been found to influence RIF (Saunders et al., 2009). In a modified version of the retrieval-practice paradigm, participants were presented with word category-exemplar pairs. Then they were split into three groups for the intermediate phase, in which there were differences in how some of the category-exemplar pairs were practiced. One group was given category cues and word stems to complete (retrieval practice condition), the second group was given exemplars and had to retrieve the associated category cues (the representation condition) and the last group engaged in mental imagery for details of the category-exemplar pairs (the mental imagery condition). Participants in this last group were also asked to rate the vividness of their mental imagery using a variation of the VVIQ scale. Then, participants in all groups completed a category cued recall task. It was found that those in the mental imagery condition had similar levels of retrieval-induced forgetting as those in the retrieval practice condition, but there no relationship between the vividness of the mental imagery (as measured by the VVIQ scale) and the amount of retrieval-induced forgetting (Saunders et al., 2009). While this study suggests that mental imagery can influence inhibition in memory, questions remain about the relationship between general mental imagery ability and inhibition (especially in tasks that do not explicitly call for visualization strategies), and whether this relationship exists in tasks using visual stimuli. Therefore, the current study aimed to understand whether individuals who have higher mental imagery ability show either increased accuracy or increased inhibition in the distorted-item paradigm and with visual stimuli.

Furthermore, as we used facial stimuli in our distorted-item paradigm, we were also interested the relationship between facial recognition ability (i.e., another individual difference related to detailed visualization) and both accuracy and inhibitory processing in memory. In particular, we assessed whether individuals who have higher levels of face recognition ability (i.e., the ability to visualize differences in faces) also have increased memory accuracy and/or increased inhibition during our distorted-item paradigm. One classic test of facial recognition is the Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006). The CFMT involves showing participants a series of photos of individual people and then asking them to recognize those faces later on among a set of distractor faces (e.g., from various viewpoints, such as left third profile, frontal view, and right third profile) or under different conditions (e.g., the same face using a different pose or under different lighting conditions). It is a leading measure for facial recognition ability and often used to assess those with prosopagnosia (i.e., the neurological condition in which people are not able to recognize familiar faces; Balas & Saville, 2015; Duchaine & Nakayama, 2006; Gray et al., 2017; Grüter et al., 2009; Hedley et al., 2011; Miller & Saygin, 2013; Shah et al., 2015; Tree & Wilkie, 2010). Therefore, the ability to discriminate between faces is an essential component of being able to memorize them and may influence what specific facial details are later retrieved.

As mental imagery and facial recognition are both cognitive processes that involve detailed visualization, we investigated whether these

individual differences influence memory accuracy and unintentional inhibition during memory retrieval. Participants completed both the VVIQ and the CFMT to assess individual differences in mental imagery and facial recognition, as well as our distorted-item paradigm to test for memory accuracy and inhibition. To anticipate the results, we replicated our original findings where we show inhibition of highly similar faces in memory and, further, we found that neither VVIQ or CFMT scores were associated with memory inhibition. However, we did find a relationship between CFMT scores and memory accuracy. This suggests that accurately recollecting faces may rely on how well individuals can visualize facial details, but that inhibition during memory retrieval is likely an unintentional process that is unrelated to how well individuals can voluntarily form detailed visualizations.

## Methods

### Data availability

The stimuli and data for this study are available to download at the following link. <https://osf.io/8vqt7/>.

### Participants

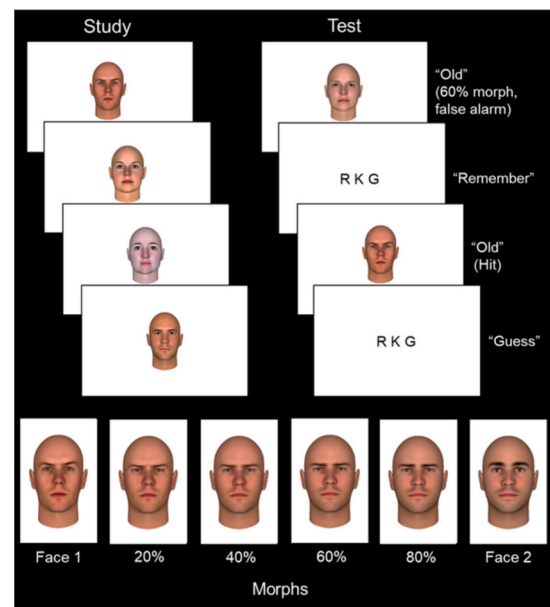
A total of 176 Worcester State University (WSU) students aged 18 to 65 (139 females, 36 males, and one participant who did not provide a gender;  $M = 20.64$  years) participated in the study. Fourteen participants were excluded: two participants were excluded because of technical computer issues and twelve participants were excluded due to lack of responses (e.g., there were no “old” responses to one or more face types). This sample size was determined based on previous research by Jeye et al. (2020) to replicate the original inhibitory results of the study using the distorted-item memory paradigm (i.e., comparing percent “old” responses between 20 % and 40 % morphs). A power analysis (G\*Power; Faul et al., 2007) indicated that a sample size of 156 would be needed, assuming power = .8, a small effect size (Cohen’s  $d = .20$ ), and  $\alpha = .05$ , with a one-tailed  $t$ -test (as the direction of the critical comparisons was known). The WSU Institutional Review Board approved the protocol and informed consent was obtained from participants prior to beginning the study. Students received research credit following participation in the study.

### Procedure

#### Distorted-Item memory paradigm

This paradigm is a modified replication of that used by Jeye et al. (2020). Each participant completed a one-third length practice run and two full length runs. A full run consisted of a study and test phase. During the study phase, participants were sequentially presented with 20 neutral Caucasian faces (10 females, 10 males) at the center of the screen, and they were instructed to remember the faces. Each face was randomly presented three times, however, no more than two male or two female faces were presented in sequence. Participants were informed that the faces would be repeated randomly three times during the study phase and that the purpose of this was to boost their memory for the faces. All faces were unique (that is, faces were not repeated across runs). Each face was presented for 2.5 s, after which a blank screen was presented for 0.5 s.

After the conclusion of the study phase, there was an 8 s delay, during which a reminder of task instructions appeared on the screen. The test phase of each full-length run consisted of 24 faces (12 male, 12 female), which were, once again, sequentially presented at the center of the screen. Within these faces were old, related, and new faces (see Fig. 1 for an example of related faces). Related faces were created by morphing together old and uniquely new faces in increments of 20 % (i.e., 20 %, 40 %, 60 %, 80 % morphs). The test phase consisted of four old faces, four faces of each type of related face, and four new faces. Participants



**Fig. 1.** Example of the experimental set-up for the distorted-item paradigm. Top. In the study phase, neutral Caucasian faces were presented in the center of the screen. In the test phase, old faces, related faces, and new faces were presented and participants classified each face as “old” or “new” followed by a “remember”–“know”–“guess” rating. Bottom. An example of the face stimuli used in the test phase.

were not informed about how many of each type of face they would be presented with during the test phase. The faces (old or related) presented in the test phase were only associated with one old face that had appeared during the study phase (i.e., if shown a 40 % morph of a particular face during the test phase, no other morph type of that face would be shown). Faces were pseudo-randomized and no more than two faces of a given type were presented sequentially. For additional information on face stimuli construction, see Jeye et al. (2020). A perceptual follow-up study determined that participants were able to perceive critical differences between old and 20 % morphs (see [Supplementary Material](#) for more information).

During the test phase, each face was presented for 3 s, after which a memory strength rating reminder was presented for 2.5 s, followed by a 0.5 s blank screen. While the faces were on the screen, participants were instructed to make “old”–“new” recognition judgements. An “old” response indicated the face was the same as a face from the study phase, whereas a “new” response indicated the face was not seen previously or was similar to one seen during the study phase. Participants were told that they would be presented with faces that would be very similar to those seen in the study phase, but that they should respond with “old” only if the face was the same as a face shown during the study phase. This was followed by a memory strength judgment where participants gave a “remember”, “know”, or “guess” response. Participants were instructed to selected “remember” if they could recall specific details of the face, “know” if they could not recall specific details of the face but were sure that it was presented (or not), during the study phase, and “guess” if they were not sure whether the face was presented during the study phase. To respond, participants pressed buttons on the computer keyboard (with the hand of their choice), using keys 1, 2, and 3. Sets of faces were counterbalanced across participants using a Latin square design, and stimuli were presented on Dell desktop computers using E-prime software (Psychology Software Tools, Pittsburgh, PA).

#### Cambridge face memory test

To assess individual differences in face recognition, the Cambridge Face Memory Test was used (Duchaine & Nakayama, 2006). This test

consists of four stages (practice, introduction/same images, novel images and novel images with noise). In the practice stage participants gained familiarity with the task via cartoon faces. Participants were instructed to memorize the following faces and were shown three study images of Bart Simpson for three seconds each: a left one-third profile, a frontal view and a right one-third profile. A test item consisting of one of the study images of Bart Simpson and two other cartoon faces were then presented and participants indicated which face they have seen before. This was followed by two additional test items, each which had one study face and two distractor faces. The introduction stage was nearly identical to the practice stage; however, either photographs of men's faces or computer-generated men's faces were used instead of cartoons. There were six target faces in total. In the novel images stage, participants were shown one image consisting of frontal shots of novel images of the six target faces (e.g., the same face using a different pose or under different lighting conditions), which they were given 20 s to review. Participants then went through 30-forced choice test items, each consisting of two distractor items and one study item, and, once again, they were instructed to select the study item. The last stage was the novel images with noise, which was nearly identical to the novel images stage. Participants viewed the same frontal images of the target faces, and then went through 24 test items. However, in contrast with the novel image stage, the test items had different levels of white noise added to them. Scores on the CFMT could range from 0 to 72. The CFMT was displayed on Dell desktop computers through the Test My Brain Initiative (<https://testmybrain.org/>; Germine et al., 2012).

The CFMT has demonstrated strong reliability and validity as a measure of facial recognition ability. In particular, studies report Cronbach's alpha values typically ranging from 0.85 to 0.90 (Bowles et al., 2009; Wilmer et al., 2012). Relatedly, the norms for the CFMT have been assessed for age, sex and testing country (Bowles et al., 2009), and several versions of the test exist exploring differences in race/ethnicity (e.g., the CFMT-Chinese; McKone et al., 2017) and gender (Arrington et al., 2022).

#### *Vividness of visual imagery questionnaire*

To assess visual mental imagery, the Vividness of Visual Imagery Questionnaire (VVIQ) was used (Marks, 1973). The questionnaire included 16 different items which are separated in blocks of four. Each block included a one-sentence theme (e.g., "For items 13–16, think of a country scene which involves trees, mountains, and a lake. Consider the picture that comes before your mind's eye."), followed by four items which narrate said themes. Participants were asked to attempt to create a visual mental image of each item and rate its vividness on a five-point scale (1 = Perfectly clear and as vivid as normal vision, 2 = Clear and reasonably vivid, 3 = Moderately clear and vivid, 4 = Vague and dim, 5 = No image at all, you only "know" that you are thinking of the object). Thus, scores ranged from 16 (superior visual mental imagery) to 80 (poor visual mental imagery). Participants were not persuaded to use any particular technique to create mental imagery (e.g., keeping their eyes opened or closed). Participants completed the VVIQ using a pen and paper and were scored by the first author or research assistants.

The VVIQ has also demonstrated to be a reliable measure of mental imagery ability with Cronbach's alpha values typically in the .76–.90 range (for review see Suica et al., 2022). Moreover, the VVIQ has been shown to have high test-retest reliability and construct validity (McKelvie, 1995; Campos and Pérez-Fabello, 2009).

#### *Analyses*

##### *Behavioral analysis of distorted-item paradigm*

Primary data analyses for the distorted-item paradigm included calculating the percentage of "old" responses out of the total number of responses for each type of face (old faces, each type of related face, and new faces), collapsing across memory strength judgments. To assess overall differences in the "old" response rate across each face type, we

first ran a repeated-measures ANOVA. Then to replicate our original findings as shown in Jeye et al. (2020) we focused on two specific comparisons of interest using paired *t*-tests: 1) comparing the "old" response rate for old faces to the "old" response rate for the 20 % morphs to assess detailed memory retrieval and 2) comparing the "old" response rate for 20 % morphs to the "old" response rate for 40 % morphs to assess whether there were inhibitory effects. A *d'* analysis was also conducted to ensure the memory effects were not due to response biases. Cohen's *d* was used to measure effect size and reported for significant results.

A secondary follow-up analysis was conducted based on the memory strength judgments to assess whether the effects differed as a function of memory strength level. Specifically, the percentage of "old" responses for each face type (i.e., old faces, 20 %, 40 %, 60 %, 80 % morphs, and new faces) was computed for each memory strength level (i.e., "remember", "know", and "guess"). Since our comparisons of interest were between 1) old faces and 20 % morphs and 2) 20 % and 40 % morphs, we first assessed whether the percent "old" responses were different between old faces and 20 % morphs across "remember", "know" and "guess" responses using a repeated-measures ANOVA. Additionally, as we knew the direction of the comparison from our primary analyses, we ran a series of one-tailed paired sample *t*-tests between old faces and 20 % morphs at each memory strength level. We followed a similar procedure to assess the differences between "old" response rates for 20 % and 40 % morphs for each memory strength level. Lastly, we also calculated a corrected familiarity score for each face type using the following equation: (percent "old" response for "know" judgments)/(1 – percent "old" response for "remember" judgments). This was to account for the fact that recollection (represented by "remember" responses) and familiarity (represented by "know" responses) may not be mutually exclusive (Yonelinas & Jacoby, 1995).

##### *Individual differences correlational analyses*

Additionally, to assess whether individual differences in face recognition and mental imagery ability influenced long-term face memory specificity, we performed a series of planned correlations. First, we calculated a memory accuracy score for each participant (which was the difference between the percent "old" response for old faces and the percent "old" response for 20 % morphs, collapsing across memory strength judgments). Using a Pearson correlation, we then assessed whether this score for each participant was associated with scores on the CFMT and VVIQ. Second, we computed a memory inhibition score for each participant (which was the difference between the percent "old" response rate for 40 % morphs and the percent "old" response rate for 20 % morphs, collapsing across memory strength judgments) and assessed whether this inhibition score was correlated with scores on the CFMT and VVIQ. We also determined whether these correlations were significantly different from each other by converting each correlation coefficient into a *z*-score using Fisher's *r*-to-*z* transformation, computing the asymptotic covariance of the estimates and, lastly, using these in an asymptotic *z*-test (Lee & Preacher, 2013).

Furthermore, we investigated the correlation between scores on the CFMT and VVIQ. Previous research suggests that there may be a relationship between intentional mental imagery and facial recognition ability (Grüter et al., 2009). Thus, we aimed to examine this association in the present study. Finally, we examined whether participants' memory accuracy score was correlated with their memory inhibition score during the distorted-item paradigm. That is, do people who more accurately distinguish old faces from highly related morphs demonstrate more inhibition during memory retrieval. In order to assess whether this correlation was dependent on CFMT and VVIQ scores, we ran a partial correlation between memory accuracy and memory inhibition scores controlling for CFMT and VVIQ scores. For any null results, we conducted a Bayesian analysis using a two-sided alternative hypothesis with prior (default) distribution values of  $-1$  to  $1$ . All analyses were conducted using JASP (Version 0.19.0).



## Results

Overall, we found a significant difference in the percent “old” response across each level of face type ( $F(4.45, 716.75) = 73.14, p < .001, \eta^2 = .312$ ; Greenhouse-Geisser corrected; Supplementary Table 1). Memory representations for the faces were very detailed as the “old” response rate for old faces was significantly higher than “old” response rate for 20 % morphs ( $t(161) = 7.68, p < .001, d = .78$ , Bonferroni corrected; Fig. 2). This indicates that participants were able to correctly reject closely related items. Furthermore, the “old” response rate for 20 % morphs was significantly lower than “old” response rate for 40 % morphs ( $t(161) = 4.56, p < .001, d = .36$ , Bonferroni corrected; Fig. 2). This can be assumed to reflect memory inhibition of closely related faces. A  $d'$  analysis demonstrated a similar pattern of results (see Supplementary Fig. S1 and Supplementary Table 2), as the 20 % morphs  $d'$  was significantly lower than that for both the old faces ( $t(161) = 7.31, p < .001, d = .56$ , Bonferroni corrected) and 40 % morphs ( $t(161) = 4.18, p < .001, d = .25$ , Bonferroni corrected).

We also investigated this pattern of results as a function of memory strength. That is, we calculated the percent “old” response rate for each face type across “remember”, “know” and “guess” judgments to examine whether detailed memory retrieval and inhibition varied depending on memory strength. Overall, in terms of memory accuracy, there was no difference in the percent “old” response between old faces and 20 % morphs across memory strength judgments ( $F(2, 84) < 1$ ). However, follow-up analyses assessing each memory strength level individually found evidence of detailed memory retrieval for both “remember” and “know” judgments. That is, for both “remember” and “know” judgments the percent “old” response was significantly different between old faces and 20 % morphs (for “remember” responses,  $t(123) = 3.74, p < .001, d = .34$ ; for “know” responses,  $t(124) = 3.50, p < .001, d = .31$ ; Supplementary Fig. S2). This memory accuracy effect was not observed for “guess” responses ( $t(54) = 1.58, p = .06, d = .21$ ; Supplementary Fig. S2). This relationship was also observed when using a corrected familiarity score for old faces and 20 % morphs ( $t(34) = 3.71, p < .001, d = .63$ ).

Similarly, for memory inhibition, we did not observe a significant interaction between percent “old” response for 20 % and 40 % morphs as a function of memory strength ( $F(2, 96) < 1$ ). Our follow-up analyses revealed that for “know” judgments the percent “old” response was significantly lower for 20 % morphs than 40 % morphs ( $t(121) = 1.93, p = .028, d = -.017$ ). This memory inhibition was not observed for either “remember” ( $t(119) = 1.47, p = .072, d = -.13$ ) or “guess” ( $t(72) = 1.38, p = .086, d = -.16$ ) judgments. However, significant memory inhibition was also not observed when using a corrected familiarity score to

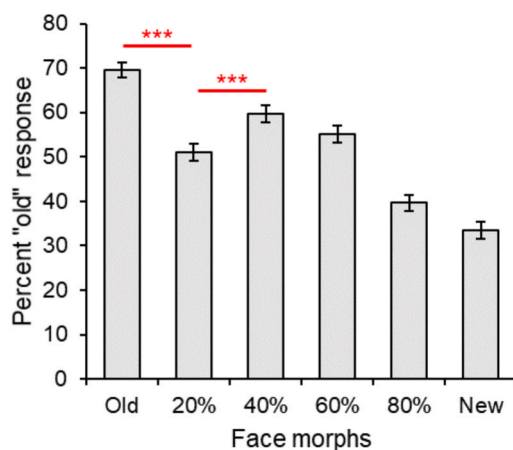


Fig. 2. The percent “old” responses for old faces, related faces (i.e., 20 %, 40 %, 60 %, 80 % morphs), and new faces in the distorted-item paradigm. Error bars represent standard error, \*\*\* =  $p < .001$ .

compare 20 % and 40 % morphs ( $t(42) < 1$ ). Still, these findings suggest that inhibition effects may be related to memory strength, particularly for familiar items.

In terms of the relationship between facial recognition and long-term face memory, CFMT scores ( $M = 56.414, SD = 9.10$ ; Supplementary Table 3) were significantly correlated with memory accuracy ( $r(160) = .26, p < .001$ ; Fig. 3). However, CFMT scores were not significantly correlated with inhibition during memory retrieval ( $r(160) = .04, p = .60, BF_{10} < 1$ ; Fig. 3). Additionally, there was a significant difference between these correlations ( $z = 2.66, p = .008$ ). This suggests that detailed face memory retrieval, but not inhibition, depends on facial recognition ability.

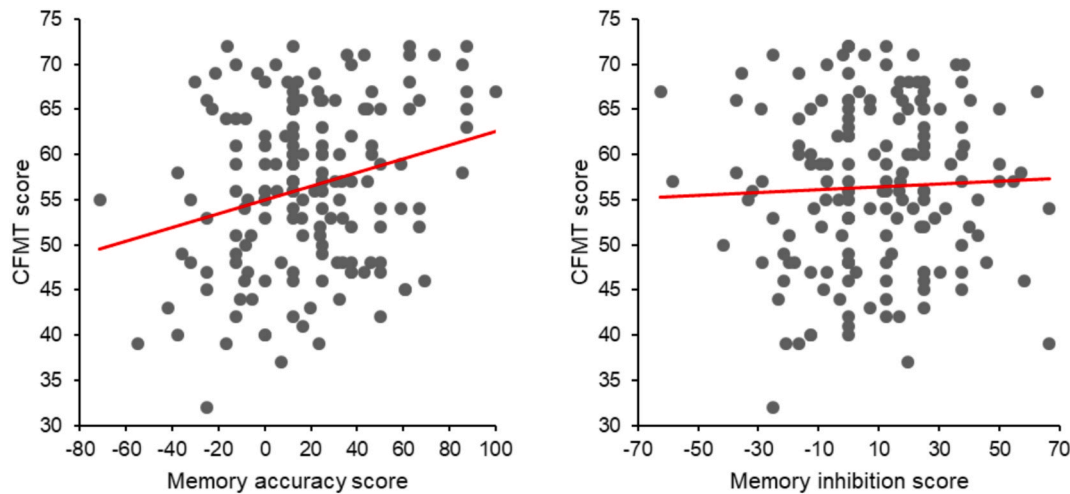
On the other hand, mental imagery ability was not found to be related to either detailed facial memory retrieval or inhibition in memory. VVIQ scores ( $M = 34.65, SD = 10.81$ , Cronbach’s alpha = .885; Supplementary Table 3) were not associated with memory accuracy scores ( $r(160) = .03, p = .76, BF_{10} < 1$ ) or inhibition scores ( $r(160) = -.06, p = .44, BF_{10} < 1$ ; Fig. 4). These correlations were also not significantly different ( $z = 1.07, p = .29$ ). Moreover, we also found no relationship between VVIQ score and CFMT score ( $r(160) = -.08, p = .29, BF_{10} < 1$ ; Supplementary Fig. S3).

To further investigate whether participants who had more correct detailed memories also demonstrated more inhibition during memory retrieval during the distorted-item paradigm, we examined the relationship between memory accuracy and memory inhibition scores. We found a significant correlation between memory accuracy scores and memory inhibition scores ( $r(160) = .43, p < .001$ ; Supplemental Fig. S4). A partial correlation analysis was also conducted to assess this relationship between memory accuracy and memory inhibition scores while controlling for CFMT and VVIQ scores. This correlation was found to be significant ( $r(160) = .44, p < .001$ ). This indicates that detailed memory accuracy may be linked to inhibitory processes that are not dependent on cognitive visualization strategies such as those used in the CFMT and VVIQ. To assess the reliability of the memory accuracy and memory inhibition scores, we performed a split-half analysis by randomly selecting and comparing the percent “old” responses for half of the response trials at each morph level. For the memory accuracy score, the split-half reliability analysis indicated a correlation of  $r(160) = .24$ , with a Spearman–Brown correction reliability coefficient of  $r(160) = .39$ . For the memory inhibition score, the split-half reliability analysis indicated a correlation of  $r(160) = .09$ , with a Spearman–Brown correction reliability coefficient of  $r(160) = .21$ .

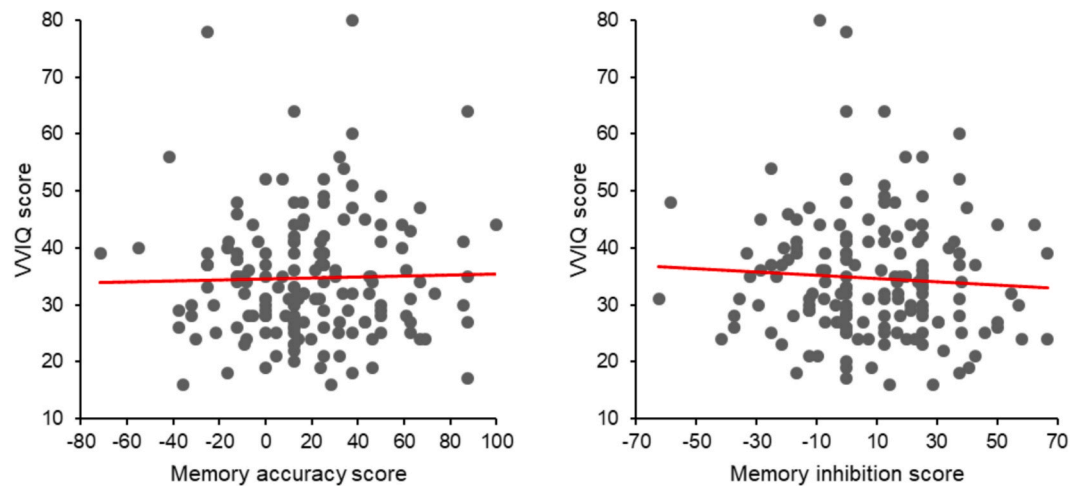
Furthermore, we reanalyzed the data from Jeye et al. (2020) and found significant correlations between memory accuracy scores and memory inhibition scores in both of those experiments ( $r(104) = .52, p < .001$  in Experiment 1;  $r(94) = .32, p < .01$  in Experiment 2; Supplementary Fig. S4). As there were no differences in the correlation values between experiments (all  $ps > .05$ ), we collapsed across all experiments using the distorted-item paradigm. That is, across three experiments (over 350 participants between the current experiment and the previous experiments from Jeye et al., 2020) we found a significant correlation between how well participants accurately remember old faces (as compared to highly similar morphs) and the amount of inhibition that acts on these highly similar morphs ( $r(293) = .43, p < .001$ ; Fig. 5). These results indicate that retrieving detailed memories is associated with unintentional inhibition of competing information in memory.

## Discussion

The present study investigated whether individual differences in face recognition and mental imagery ability influenced inhibition in long-term face memory specificity. Our findings reveal that intentional mental imagery ability (as measured by the VVIQ) is not associated with inhibition or detailed memory retrieval in long-term facial memory. We also did not observe a significant correlation between inhibition in long-term memory and face recognition ability (as measured by the CFMT).



**Fig. 3.** Left. The relationship between CFMT score and memory accuracy score (i.e., the difference between the “old” response rate for old faces and the “old” response rate for 20% morphs). Right. The relationship between CFMT score and memory inhibition score (i.e., the difference between the “old” response rate for 40% morphs and the “old” response rate for 20% morphs).



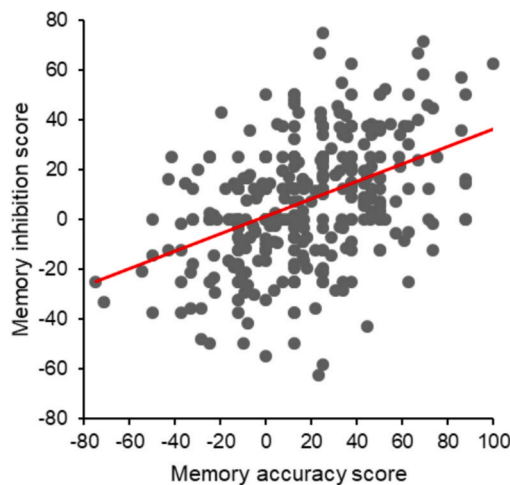
**Fig. 4.** Left. The relationship between VVIQ score and memory accuracy score (i.e., the difference between the “old” response rate for old faces and the “old” response rate for 20% morphs). Right. The relationship between VVIQ score and memory inhibition score (i.e., the difference between the “old” response rate for 40% morphs and the “old” response rate for 20% morphs).

However, a significant relationship was found between face recognition and memory accuracy. That is, individuals with high scores on the CFMT were better able to discriminate between old and highly similar faces (i.e., 20 % morphs) in the distorted-item paradigm. Furthermore, we also found a significant correlation between memory accuracy and memory inhibition in our distorted-item paradigm (in both the current experiment and those reported previously by Jeye et al., 2020). Taken together, these results indicate that long-term memory specificity depends on unintentional inhibition that is independent of intentional cognitive processes related to visualization ability (i.e., mental image and facial recognition).

Critically, we replicated the original findings of Jeye et al. (2020) which found that inhibition was involved in face memory specificity. In this paradigm, the “old” response rate for old faces was significantly higher than that of 20 % morphs. This difference in percent “old” response between old faces and 20 % morphs demonstrates detailed memory accuracy for face stimuli, which aligns with previous research assessing the precision of visual long-term memory (Brady et al., 2008; Brady et al., 2013). Furthermore, the “old” response rate for closely related faces (i.e., 20 % morphs) was significantly lower than that of distantly related faces (i.e., 40 % morphs). As originally described by

Jeye et al. (2020), this pattern of results is similar to those observed in center-surround suppression of related or distracting items in attention and working memory paradigms (Dagenbach & Carr, 1994; Kiyonaga & Egner, 2016; Slotnick et al., 2002; Slotnick et al., 2003; Störmer and Alvarez, 2014). This suggests that there is an unintentional inhibitory mechanism that acts on closely related items in long-term memory, which may help individuals recall specific facial details.

Furthermore, there is growing evidence that demonstrates the role of unintentional inhibitory processing in visual long-term memory more broadly (Anderson et al., 1994; Healey et al., 2014; Ngo & Hasher, 2017). That is, there is inhibitory processing that occurs when individuals retrieve a studied item among related items without an explicit cue to either remember or forget each item. This has been demonstrated with semantic stimuli (e.g., related word pairs), and visual stimuli (Maxcey & Woodman, 2014; Waldhauser et al., 2012; Wimber et al., 2015), including faces (Ferreira et al., 2014; Ferreira et al., 2019; Rugo et al., 2017). Additionally, research has examined how the number and similarity between items can lead to changes in memory, such as when the memories for items are blended together (i.e., “attraction”) or exaggerated (i.e., “repulsion”; Chanale et al., 2021; Drascher & Kuhl, 2022; Scotti et al., 2021a,b). In particular, it is thought that this



**Fig. 5.** The relationship between memory accuracy scores and memory inhibition scores across all participants in the distorted-item paradigm with facial stimuli (i.e., the current experiment and Experiments 1 and 2 from Jeye et al., 2020).

“repulsion” helps to minimize errors between competing similar memories. Taken together, this suggests that unintentional inhibitory processing may modulate visual long-term memory and that it may be triggered by the relatedness between memories.

While other studies have investigated the specificity of visual long-term memory, ours are the first, to our knowledge, to show evidence of center-surround suppression (Jeye et al., 2020; Jeye et al., 2024). This might be due, in part, to overall limitations in stimulus/study design. For example, other studies have used face morphs to investigate differences in long-term memory (Turney & Dennis, 2017). However, this research used different increments in the perceptual relatedness between the face morphs to ours (e.g., we used smaller increments of 20 %). It is possible that inhibition works at category boundaries (similar to what is observed in working memory studies; Fang et al., 2019; Johnson & Anderson, 2004; Martin & Chao, 2001; Yang & Mo, 2017), and, since faces have smaller category boundaries, using face morphs with larger differences may not be sensitive enough to probe inhibitory processing. Relatedly, more recent research has used alternative assessments of memory specificity, such as continuous scales or drawing to measure color, orientation and/or location accuracy (Bainbridge, Kwok & Baker, 2021; Bainbridge et al., 2021b; Berens et al., 2020; Brady et al., 2013; Cooper & Ritchey, 2019; Harlow & Yonelinas, 2016; Miner et al., 2020; Richter et al., 2016). Continuous measurements (such as when participants use a color wheel to indicate the color of previously seen items), for example, are inherently different than our recognition judgements (i.e., “old” or “new” responses), and therefore, may not capture inhibitory processing in memory. Even in studies that use more traditional recognition judgements there are differences in the stimuli used and types of recognition judgements made. For instance, research using the mnemonic similarity task, which assesses memory discrimination (i.e., the ability to distinguish between similar items; Stark et al., 2019), uses images of real-world objects and asks participants to make “old,” “similar,” or “new” judgments during the testing phase (where participants are shown old objects, lure/similar objects, or completely new items). In particular, it would be difficult to morph these real-world objects incrementally along a consistent spectrum of perceptual similarity, and thus these stimuli may not be able to capture subtle variations in memory specificity. Furthermore, the use of “old,” “similar,” or “new” judgments may limit the ability to assess the pattern of center-surround suppression that we observed in our task for inhibitory processing. Future work should continue to examine how differences in stimulus and task design impact inhibition in visual long-term memory specificity.

Our results also demonstrate that inhibition may be related to

memory strength. In the current paradigm, participants were asked to make a “remember,” “know,” or “guess” judgment after their initial “old”–“new” response. These judgments are a measure of the amount of subjective detail a participant can retrieve. That is, a “remember” response is indicative of recollection (retrieval with specific details) and a “know” response reflects familiarity (retrieval without specific details; Slotnick, 2013; Yonelinas et al., 2010). We found that memory performance is related to both memory accuracy (as shown by a significant difference in the “old” response rate between old faces and 20 %) and memory inhibition (as shown by a significant difference in the “old” response rate between 20 % and 40 % morphs). This shows that inhibitory processing in long-term memory may be flexibly recruited depending on memory strength and may not be necessary for the conscious experience of retrieving specific details (as we did not see this pattern of results for “remember” responses).

One limitation of the current paradigm is that it used computerized face stimuli. Thus, there is a question of whether this pattern of inhibition in long-term face memory applies to real human faces, and, further, whether general facial recognition ability (i.e., the ability to perceive differences between faces) is related to inhibition in facial memory specificity. In particular, when assessing the reliability of our memory accuracy and memory inhibition scores in the current distorted-item paradigm, we found relatively low split-half reliability estimates. It is possible that this is due to the use of computerized faces, which may be processed differently than real human faces. Additionally, the current results indicate that general facial recognition ability (as measured by the CFMT) is not associated with inhibitory processing. This is similar to our findings related to memory strength mentioned previously. On the other hand, we did find that face recognition ability was significantly associated with memory accuracy (i.e., the ability to discriminate between old and highly related faces in memory). This finding indicates that one’s ability to remember specific faces may depend on one’s ability to perceive differences in them, and that this may be a conscious process. This relationship further validates the original distorted-item paradigm by Jeye et al. (2020), as memory scores determined with the computerized face stimuli significantly correlated with scores on the CFMT (an empirically tested measure for assessing face recognition ability; Duchaine & Nakayama, 2006).

Another limitation of the current research is that both the stimuli from the memory paradigm and the CFMT were that of Caucasian faces. Future research should aim to investigate the implication of the own-race bias (that is, where unfamiliar faces from other racial groups are remembered less than that of one’s own race group; Meissner & Brigham, 2001) in both face recognition ability and inhibition in long-term face memory specificity by using more racially diverse samples and stimuli. It may be that individuals of a certain racial group would experience more inhibition for faces of their own racial group, which would help them remember those specific faces more than faces of a different racial group. However, it could also be hypothesized that inhibition could be needed for people to recognize faces outside of their racial group in order to help them select the correct face from memory.

Furthermore, the current relationship between face recognition ability and memory accuracy is supported by previous research in individuals with prosopagnosia (i.e., individuals with a congenital inability to recognize familiar faces). Parketny et al. (2015) employed the use of a long-term facial memory paradigm to investigate event related potentials (ERPs) in developmental prosopagnosics and controls. They found a delayed N250 activation (a marker of a stored visual facial memory representation) and delayed P600 activation (a marker associated with conscious awareness and recognition of a specific face) in developmental prosopagnosics. This demonstrates that those with severe face recognition deficits also experience delays in activation of visual facial memories. Furthermore, it has been shown that individuals with developmental prosopagnosia also experience deficits in short-term facial memory, where developmental prosopagnosics took longer and were less accurate in their responses in a face-matching task (Shah et al.,



2015). Taken together, there is both behavioral and ERP evidence for the relationship found between face recognition and facial memory. Future research should investigate the neural underpinnings of the connection between the facial perception and face memory specificity, especially in the brain regions involved with each.

Another aim of the current study was to assess whether individual differences in intentional mental imagery ability would influence long-term face memory specificity, as previous research indicated that there is a relationship between mental imagery and memory (Bainbridge et al., 2021a; Brewer & Pani, 1996; Butler et al., 2016; Greenberg & Knowlton, 2014; Rubin, 2006; Vannucci et al., 2016; Williams et al., 1999). However, we found no relationship between VVIQ scores and memory inhibition or between VVIQ scores and memory accuracy. This further suggests that inhibition in memory occurs unintentionally. While this seems to contradict previous research on this topic, it is important to note that the majority of this research used explicit cues related to mental imagery. For example, Saunders et al. (2009) included a mental imagery condition in a modified retrieval-practice paradigm in which participants were instructed to imagine word-pair associations during the intermediate practice phase. They found that participants who engaged in this mental imagery condition showed evidence of RIF. Additionally, other research investigating the relationship between mental imagery and memory did not directly look at the role of inhibition during the retrieval process. For instance, Bainbridge et al. (2021a) used real world scenes and had participants re-draw them from memory and Butler et al. (2016) had participants recall recent autobiographical events in response to a word cue. Both found a relationship between mental imagery ability and memory. It is also possible we did not see a relationship between mental imagery and memory inhibition because imagery may not rely on accurately recalling details of the representation (but instead may rely on subjective feelings of confidence). Future research will need to investigate under what conditions confidence and vividness are connected and how these measures impact memory specificity.

Lastly, we found that scores on the CFMT and VVIQ were not related. Research on mental imagery and face recognition has not reached a consensus on if, or how, these cognitive abilities relate. Milton et al. (2021) found that although individuals with aphantasia (i.e., individuals with an inability to create mental images) perceived their face recognition ability to be worse than both individuals with hyperphantasia (i.e., people with a superior ability to create mental images) and controls (i.e., people of average mental imagery ability), there were no significant differences in behavioral performance between groups on a face recognition task. On the other hand, there is some evidence to suggest that individuals with congenital prosopagnosia experience some visual mental imagery deficits, however, these deficits seem to be specific to faces only (and not for other visual stimuli). For example, Tree and Wilkie (2010) found that although object and color imagery was preserved, face imagery was impaired in individuals with congenital prosopagnosia. Furthermore, Grüter et al. (2009) showed that individuals with congenital prosopagnosia had preserved mental imagery for houses but impaired face imagery. Thus, there seems to be a relationship between mental imagery and face recognition ability, however, it seems to be face specific. The current study did not specifically investigate imagery for just faces (as the VVIQ has questions related to different types of visual imagery), and therefore, it is possible that this is why no relationship was found.

Taken together, the absence of significant findings using the VVIQ raises questions about whether our null results might be attributed to the type of stimuli we used or limitations of the measure itself. For example, faces, as stimuli, are processed differently from other types of visual items, such as objects or scenes (Haxby et al., 2000), and this unique processing could have contributed to the lack of observed relationships between mental imagery and memory. It is possible that if we had used more detailed and/or varied stimuli (such as scenes) that we may have observed a significant relationship between mental imagery and

memory specificity. Additionally, while the VVIQ is a widely used measure of mental imagery, it is relatively “crude,” relying predominantly on subjective, self-reported vividness of scenes rather than other forms of imagery. As mentioned previously, recent advancements, such as drawing-based methods (e.g., Bainbridge et al., 2021a), offer more nuanced ways to assess mental imagery and memory and have yielded different results. Future research should explore the relationship between memory and imagery using more specific measures tailored to particular stimuli, including faces. This could help determine if imagery abilities may vary across different categories of visual stimuli. In terms of the current study, our results indicate that conscious mental imagery ability may not be necessarily related to facial memory specificity.

Overall, the current study found no association between intentional detailed visualization (e.g., mental imagery ability and facial recognition) and unintentional inhibition in long-term face memory specificity. This indicates that inhibition acts as a non-conscious process during memory retrieval. Furthermore, future research should investigate what other individual differences, such as in cognitive control and mechanisms related to perception and attention, could also influence inhibition in long-term face memory specificity. For instance, this unintentional inhibitory processing might be associated with individual differences in priming (a cognitive process that similarly reflects non-conscious processing of stimuli). Relatedly, future research could examine the brain timing associated with inhibition during memory retrieval within our distorted-item task. For example, research using the retrieval-practice paradigm has found an increase in alpha activity for competing memories, signifying inhibition (Waldhauser et al., 2012). In our distorted-item paradigm, we might expect an increase in alpha activity in posterior visual regions when participants view the 20 % morphs, as compared to the old faces or 40 % morphs. Furthermore, there is a growing push to research individual differences in both mental imagery ability and, separately, in facial recognition, especially with regard to practical implications such as for identity checking careers and human-artificial intelligence research (Floridou et al., 2022; White & Burton, 2022).

## Author contributions

A. R. Acevedo and B. M. Jeye developed the study design. Testing and data collection was performed by A.R. Acevedo. Analyses were performed by A. R. Acevedo and B. M. Jeye. A. R. Acevedo, B. M. Jeye and S. D. Slotnick drafted the manuscript.

## CRediT authorship contribution statement

**Aliana Rodriguez Acevedo:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Scott D. Slotnick:** Writing – review & editing, Formal analysis. **Brittany M. Jeye:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## 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.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jml.2025.104714>.



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