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Encoding-Stage Adaptation Effects: Long-Term Memory

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Abstract

Given adaptation changes perceptual experience, it probably shapes long-term memory (LTM). Across four experiments, participants were adapted to strongly gendered (male, female: Experiments 1 and 2) or aged faces (old, young: Experiments 3 and 4) *before* LTM encoding and later completed an LTM test in which the encoded faces were morphed with the opposite end of the relevant continuum. At retrieval, participants judged whether probe faces were more or less male or female or young or old than when presented during encoding. For male, female, and young faces, encoding-stage adaptation significantly shifted the point of subjective equality in the unadapted direction. Additionally, encoding-stage adaptation significantly enhanced recognition of faces during LTM retrieval. We conclude that encoding-related adaptation is reflected in LTM.

Keywords

adaptation, constancy, long-term memory, face perception, encoding, retrieval

If you have ever snorkeled among spectacularly multicolored fish and corals, your memory of the experience is probably vivid. Yet, your underwater pictures reveal blue soup. This anecdote highlights our guiding observation: Encoding-related adaptation must persist at long-term memory (LTM) retrieval.

Adaptation studies repeatedly present a stimulus feature and demonstrate shifts of perception detectible after a brief delay (reviewed in Kohn, 2007; Webster & MacLeod, 2011). This literature shows predictable distortions such that adaptation pushes perception toward the other end of a feature dimension. For example, adaptation to male faces makes androgynous faces appear female (Webster, Kaping, Mizokami, & Duhamel, 2004), and adaptation to old faces makes middle-aged faces look younger (O'Neil & Webster, 2011).

Adaptation studies have examined how changes in adaptation test duration modulate visual aftereffects, where longer adapting and shorter retrieval periods resulted in greater

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visual aftereffects (Rhodes, Jeffery, Clifford, & Leopold, 2007). Studies have also shown that aftereffects can last up to 80 min (Carbon & Leder, 2006), several days (Carbon et al., 2007), or 1 week (Carbon & Ditye, 2010).

Despite the broad scope of adaptation studies, there remains a gap in how stimuli that are distinct from adaptation are encoded and retrieved. Longer delays have been studied with highly familiar faces such as celebrities (Carbon & Ditye, 2010, 2012; Carbon et al., 2007) and the Mona Lisa (Carbon & Leder, 2006) and with novel faces (Webster & Maclin, 1999). These aftereffects have even been noted to transfer between novel test images. However, these studies have not assessed how adaptation affects the encoding and retrieval of faces distinct from the adaptation phase.

Working memory (WM) and LTM are distinguished by retrieval duration and item capacity (Baddeley, 1992; Miller, 1956; Paas, Van Gog, & Sweller, 2010; Peterson & Peterson, 1959). WM is limited to approximately four items, and almost all information will be lost within 30 s without rehearsal (Cowan, 2001), whereas LTM is accurate for thousands of items over longer time periods (Brady, Konkle, Alvarez, & Oliva, 2008; Standing, 1973). Adaptation studies have shown aftereffects after delays ranging from seconds to days, which suggests aftereffects are present in WM and LTM (Carbon & Ditye, 2010, 2012; Carbon et al., 2007). However, these studies have not included a controlled distraction task during delays to prevent rehearsal before retrieval. Because rehearsal is necessary to distinguish WM from LTM, we included a distraction task during the delay period to ensure image identities could not be rehearsed.

LTM-encoding manipulations, such as the classic levels of processing effect, predict LTM retrieval success (Craik & Lockhart, 1972). Thus, encoding-stage adaptation likely extends to LTM. Valentine's theory of norm-based coding suggests that previous visual experiences affect our perception (Valentine, 1991). These experiences shape how we code the world on the norms we encountered, especially how we perceive faces. Therefore, as previous research suggests, adaptation to certain aspects of faces, such as gender and age, affects the perception of those faces later (Short, Proietti, & Mondloch, 2015). We tested this logic by conducting four experiments using faces. In these experiments, participants were adapted to faces that varied by gender (Experiments 1 and 2) or age (Experiments 3 and 4) and later reported whether a manipulated probe was more or less gendered or aged than at encoding. In Experiments 1, 2, and 4, encoding-related adaptation caused intermediate faces to appear closer to the other end of the relevant spectrum when retrieved from LTM. Additionally, each experiment showed that recognition for encoded faces was enhanced as a result of adaptation.

Methods

Participants

Each experiment included 12 students from the University of Nevada with normal or corrected-to-normal vision (Experiment 1: mean age: 22.83 years (4.51), 5 females; Experiment 2: 23.25 years (5.0), 7 females; Experiment 3: 24.83 years (12.55), 9 females; and Experiment 4: 21.42 years (2.47), 7 females). Participants provided assent. Procedures were approved by the University Institutional Review Board.

Stimuli

Sixty pairs of male–female faces and 60 old–young pairs (age range: 15–65 years) were created in FaceGen (Singular Inversions, Canada). In Experiments 1 and 2 (male or female), each face pair belonged to the same race and age. In Experiments 3 and 4 (old or young), each face pair belonged to the same race and gender. Pairs were blended using WinMorph over 100 steps. We used Steps 0, 25, 50 (midpoint: androgynous or middle aged), 75, and 100 (strongest for the adapted feature) for each face experiment. In Experiment 3, Step 100 included faces aged 65 years and Step 0 included faces that were aged 15 years. In Experiment 4, Step 100 included faces aged 15 years and Step 1 included faces that were aged 65 years. An additional 100 strongly featured faces (note that strongly featured refers to morph Step 100) were created for each adaptation induction (male or female and old or young; see Figure 1).

Procedure

Stimuli were presented on a 15" MacBook Pro at a distance of 57 cm and programmed in Matlab (Psychophysics Toolbox; Brainard, 1997). Stimuli were presented at 9.9° × 9.9° of visual angle. Participants completed two conditions: a no-adapt and an adapt condition. The no-adapt condition was run first to prevent contamination from adaptation induction

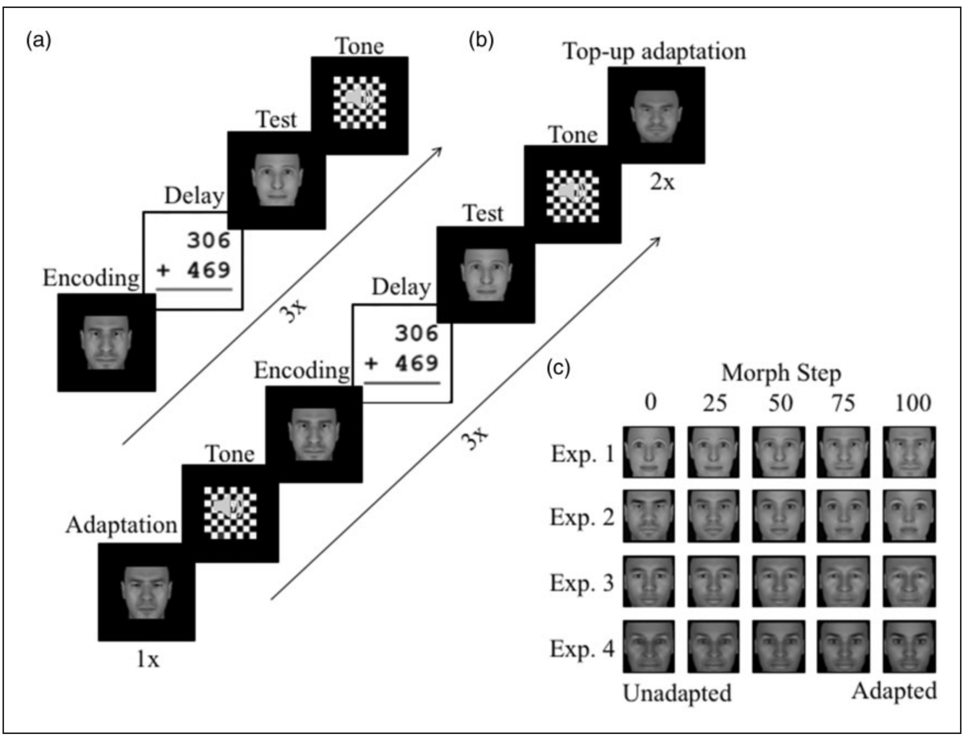

Figure 1. Experiments 1-4: task design and example stimuli. (a) No-adaptation condition. Participants encoded strongly male, female, old, or young faces (morph Step 100). During the delay, they completed a worksheet of arithmetic problems for 30 s. During testing, they judged morphs of encoded faces as more male or female and old or young than the faces presented at encoding. A checkerboard and tone distinguished a new encoding block. (b) Adaptation condition. Before encoding the faces, participants were presented with strongly male or female and old or young faces. Encoding, delay, and test phases were the same as the no-adaptation condition with the exception of top-up adaptation phase after the first and second blocks. (c) Examples of stimuli belonging to different morph steps are shown from each experiment.

(see Figure 1(a)). Participants completed three blocks of the no-adapt and adapt conditions. During each no-adapt block, participants encoded 20 strongly male (Experiment 1), female (Experiment 2), old (Experiment 3), and young (Experiment 4) faces for 500 ms per image. We chose a block paradigm where 20 faces were encoded per block to not overload memory and limit any rehearsal that may contaminate LTM with WM (Cowan, 2008). After encoding, there was a delay period (30 s) in which participants completed a separate worksheet of arithmetic problems (e.g., 306 + 469). During the delay, only instructions to complete the math worksheet were shown on the screen. At the end of the delay, a tone indicated the start of the test phase. During testing, participants made unspeeded two alternative forced choice responses to categorize whether faces from an encoded gender or age morph appeared more male or female or old or young than the encoded image. Participants pressed "m" for faces that appeared more male and "f" for the faces that appeared more female than during encoding in Experiments 1 and 2. In Experiments 3 and 4, participants pressed "o" for faces that appeared older and "y" for the faces that appeared younger. Each testing block consisted of 20 test faces, where each image belonged in the same continuum as one of the strongly featured faces presented at encoding (see Figure 1(c)). At the end of each block, a checkerboard and an auditory cue were presented (1,000 ms) to prepare participants for the next encoding block. In the no adapt blocks, total of 60 faces were encoded and tested across the three no-adapt blocks.

In the adaptation condition, participants were first adapted to 100 randomized strongly featured male or female faces (Experiments 1 and 2) and old or young faces (Experiments 3 and 4), each distinct from encoding or test images (250 ms per image, Step 100; see Figure 1(b)). This initial adaptation period was not repeated in subsequent blocks. There was, however, a "top-up" adaptation procedure interleaved before subsequent encoding blocks (as done in Kompaniez, Sawides, Marcos, & Webster, 2013). During top-up adaptation, a randomly selected range (anywhere between 16 and 32 images) of the adaptation stimuli were presented (250 ms per image; 4,000–8,000 ms total). Prior to encoding, the checkerboard and auditory cue were presented (1,000 ms) to distinguish adaptation from encoding and to prepare participants for encoding. The encoding, delay, and LTM testing blocks proceeded in the same fashion as the no-adapt condition. The checkerboard and auditory cue were presented to allow participants sufficient time to fixate for "top-up" adaptation (1,000 ms) and were again presented to distinguish "top-up" adaptation from encoding during blocks 2 and 3.

Analyses

Point of subjective equality. The point of subjective equality (PSE) reflects the morph step that individuals uniquely endorsed as equally likely to be more or less like the original stimulus. The PSE was calculated by fitting a psychometric function to the adapt and no-adapt conditions, where the x axis referred to the relevant morph continuum and the y axis referred to the percentage of responses that were judged as male or female and old or young. For example, in Figure 2, Morph 73 represents the no-adapt PSE (x axis) because it was endorsed as 50% male or female (y axis). To assess the shift postadaptation, we calculated the percentage of responses (y axis) from the psychometric curve for adaptation at the no-adapt PSE (as done in Harris & Ciaramitaro, 2016). The change in judgment between the pre- and postadaptation was determined by calculating the difference between adapt and no-adapt judgments.

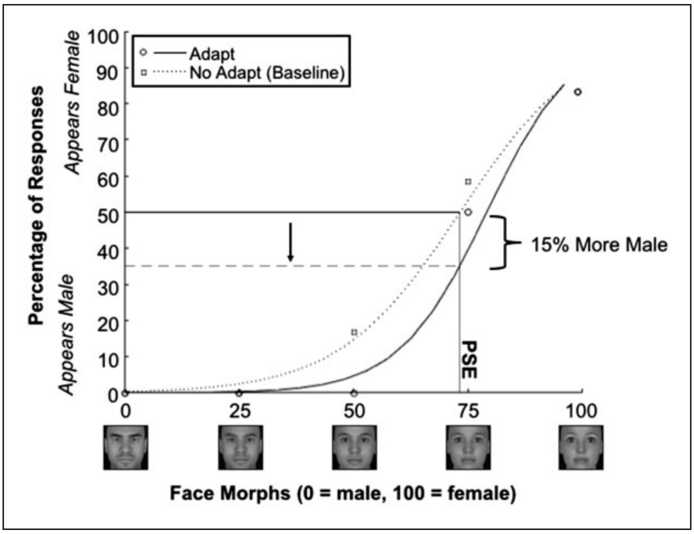

Figure 2. Psychophysical results for a single participant from Experiment 2. The *x* axis represents the morph continuum and the *y* axis represents the percentage of responses judged as male or female for each morph. The dotted curve represents the no-adapt psychometric curve, and the solid curve is the psychometric curve after the participants were adapted to female faces. The no-adapt PSE shows what morph each participant endorsed to be 50% male or female at baseline. In this example, the participant perceived Morph 73 to be 50% male and female at baseline. The shift in judgment after adaptation was calculated by assessing the predicted *y* value of the postadapt curve with the no-adapt PSE. There was a 15% *downward* shift of the perceived femaleness after adaptation, which indicates a perceptual shift toward the male (unadapted) side of the spectrum.

LTM recognition. Recognition was assessed by calculating the percentage of correct judgments relative to the image presented at encoding. First, trials where the test image was the same morph step as encoding were excluded. We then summed responses where a test probe was correctly identified relative to the encoded item. Correct judgments were divided by the sum of correct and incorrect judgments and multiplied by 100 to obtain the percentage of correct responses. The difference between adapt and no-adapt performance values was calculated to obtain a difference score.

Results

Point of subjective equality

PSE difference values were subjected to one-sample t tests comparing the differences to 0 which were significant in Experiments 1, 2, and 4 (Experiment 1: $t(11) = -3.76$, $p = .0031$; Experiment 2: $t(11) = -2.56$, $p = .027$; Experiment 3: $t(11) = -1.96$, $p = .076$; and Experiment 4: $t(11) = -4.15$, $p = .0016$). For a summary of these results (refer to Table 1). Each experiment was also subjected to one-way repeated measures analysis of variance to assess the role of block on the PSE difference between adapt and no-adapt conditions. In all experiments, there was no significant main effect of block on PSE values (Experiment 1: $F(2, 22) = 1.07$, $p = .69$, $\eta^2 = 0.02$; Experiment 2: $F(2, 22) = 0.38$, $p = .36$, $\eta^2 = 0.06$; Experiment 3: $F(2, 22) = 0.09$, $p = .99$, $\eta^2 = 0.005$; and Experiment 4: $F(2, 22) = 1.69$, $p = .21$, $\eta^2 = 0.09$).

Table 1. Experiments 1 to 4 PSE Results: Means (*SD*) and the Results of a One-Sample *t* Test Comparing the Difference in Baseline PSE Judgments Between Pre- and Postadaptation to 0.

Experiment	Adapting condition	Average difference	One-sample *t* test
1	Male	−23.70 (21.83)	$t_{11} = -3.76$, $p = .0031$
2	Female	−12.96 (17.54)	$t_{11} = -2.56$, $p = .027$
3	Old	−8.36 (14.79)	$t_{11} = -1.96$, $p = .076$
4	Young	−13.95 (11.63)	$t_{11} = -4.15$, $p = .0016$

Note. We note that a difference of 0 reflects no change in judgment pre- and postadaptation. Negative difference values represent downward shifts toward the opposite end of the relevant continuum, whereas positive difference values represent upward shifts toward the adapted side of the continuum.
PSE = point of subjective equality.

Table 2. Experiments 1 to 4 Recognition Results: Means (*SD*) and the Results of a One-Sample *t* Test Comparing the Difference in Correct Responses Before and After Adaptation.

Experiment	Adapting condition	Average difference	One-sample *t* test
1	Male	8.71 (10.24)	$t_{11} = 3.13$, $p = .01$
2	Female	4.86 (7.40)	$t_{11} = 2.28$, $p = .04$
3	Old	8.71 (10.24)	$t_{11} = 2.82$, $p = .02$
4	Young	10.07 (11.05)	$t_{11} = 3.16$, $p = .01$

Note. We note that a value of 0 indicates no difference in recognition, a positive value indicates better recognition performance after adaptation, and a negative value indicates better performance before adaptation.

Recognition

Recognition performance difference scores were compared by single-sample *t* tests showing significantly better recognition performance after adaptation (Experiment 1: $t(11) = 3.13$, $p = .01$; Experiment 2: $t(11) = 2.28$, $p = .04$; Experiment 3: $t(11) = 2.82$, $p = .02$; and Experiment 4: $t(11) = 3.16$, $p = .01$; see Table 2). A one-way repeated measures analysis of variance was conducted to assess the role of block on recognition. There was no significant main effect of block (Experiment 1: $F(2, 22) = 0.009$, $p = .99$, $\eta^2 = 0.0005$; Experiment 2: $F(2, 22) = 1.39$, $p = .27$, $\eta^2 = 0.06$; Experiment 3: $F(2, 22) = 0.15$, $p = .85$, $\eta^2 = 0.01$; and Experiment 4: $F(2, 22) = 2.05$, $p = .15$, $\eta^2 = 0.09$).

The relationship between PSE and recognition

Pearson's product–moment correlations were conducted to compare PSE shifts and recognition performance. A negative correlation indicated that a PSE shift toward the unadapted end of the relevant continuum resulted in better recognition performance for each morph step relative to the encoded morph. For each experiment, the correlation was negative and significant (Experiment 1: $r = -0.59$, $t_{10} = -2.35$, $p = .04$; Experiment 2: $r = -0.82$, $t_{10} = -4.60$, $p = .0009$; Experiment 3: $r = -0.73$, $t_{10} = -3.37$, $p = .007$; and Experiment 4: $r = -0.86$, $t_{10} = -5.38$, $p = .0003$).

Discussion

The data showed that LTM retrieval shifted toward the unadapted end of the spectrum after encoding-stage adaptation. After encoding-stage adaptation to strongly male faces, androgynous faces (as defined by the PSE) were judged as more *female* at LTM retrieval (Experiment 1) and vice versa after adaptation to female faces (Experiment 2). Similarly, a middle-aged face was endorsed as *younger* after encoding-stage adaptation to old faces (Experiment 3) and vice versa after adaptation to younger faces (Experiment 4). This effect was significant in Experiments 1, 2, and 4. Additionally, we assessed how PSE judgments changed as a function of block. Overall, there were no significant differences in PSE judgments by block, suggesting that the strength of long-term perceptual effects remained robust even as time delayed.

Most adaptation studies find changes in perception at the PSE and not elsewhere, particularly at the extremes. One reason may be that veridical memory is better for information further from the PSE and thus is unaffected by adaptation. However, information closer to the PSE is better recognized as a product of adaptation. Our data showed that probe faces were significantly better identified after adaptation. Because perceptual shifts are greater for information close to the PSE, this suggested that recognition for the more ambiguous faces was enhanced as a product of adaptation. This was verified by correlations between PSE shifts and recognition performance which were significant in all experiments. This suggests that adaptation serves to refine representations, particularly for more ambiguous information, in the long term.

Experiment 3 showed conflicting results. Although there was no difference in PSE values, the data showed that participants were significantly better at recognizing when a probe was younger than an encoded face and that the relationship between the PSE shift and recognition was significantly correlated. This suggests that both perception and veridical memory was enhanced as a function of adaptation, although there was no significant PSE shift. Because our participant pool was composed of young adults at an undergraduate institution, perhaps, there was an age bias that shifted the PSE. Specifically, because our participants are exposed to other young adults on a daily basis, their perception of our older stimuli was shaped by what they perceive daily. Previous literature supports this observation where people are better at recognizing faces in their own age cohort (Anastasi & Rhodes, 2005; Burt & Perrett, 1995). Additionally, this age bias is seen more in younger adults than older adults but not vice versa. This effect, however, is task dependent and not always present (Proietti, Macchi Cassia, & Mondloch, 2015). As the norm-based coding theory suggests, the perception of category-specific features of age may have been influenced by experience for the young adults in the current study (Short et al., 2015; Valentine, 1991).

Because visual aftereffects are robust across a range of stimuli, such as color (Webster & Mollon, 1994), grating and orientation (Maffei, Fiorentini, & Bisti, 1973), and blur (Kompaniez et al., 2013; Webster, Georgeson, & Webster, 2002; Webster & Miyahara, 1997), it is likely that our results may be generalizable to other adapting stimuli. Additionally, each experiment showed a significant correlation between PSE shift and recognition performance, where participants were better able to distinguish when test images were less male or female and less old or young than the faces they encoded after adaptation. This suggests that aftereffects may enhance representations in the long term. Our findings for gender and age extend previous findings for face distortion, where after adaptation to distorted images of famous people, participants were able to update their representation of that face and distinguish distorted faces from unadulterated faces (Carbon & Ditye, 2011; Carbon et al., 2007; Carbon & Leder, 2006). If aftereffects are powerful for other adapting stimuli, this suggests that the visual information we encounter daily constantly molds perception and memory. Overall, our data show that LTM is an important yet overlooked aspect of adaptation.

The current work was motivated by anecdotes highlighting how our encoding state shapes our later memory. These data experimentally confirm that how we perceive an event shapes LTM for it. This is consistent with the adaptation literature, which reliably finds that after adaptation to a facial feature, a neutral midpoint appears biased away from the adapting stimulus (Webster & MacLeod, 2011). The adaptation literature has been a useful tool into the neural architecture of perception, and it may be useful for understanding the warping involved in LTM.

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Declaration of Conflicting Interests

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