Distraction biases working memory for faces

Remington Mallett [1] · Anurima Mummaneni [2] · Jarrod A. Lewis-Peacock [1]

Abstract

Working memory persists in the face of distraction, yet not without consequence. Previous research has shown that memory for low-level visual features is systematically influenced by the maintenance or presentation of a similar distractor stimulus. Responses are frequently biased in stimulus space towards a perceptual distractor, though this has yet to be determined for high-level stimuli. We investigated whether these influences are shared for complex visual stimuli such as faces. To quantify response accuracies for these stimuli, we used a delayed-estimation task with a computer-generated "face space" consisting of 80 faces that varied continuously as a function of age and sex. In a set of three experiments, we found that responses for a target face held in working memory were biased towards a distractor face presented during the maintenance period. The amount of response bias did not vary as a function of distance between target and distractor. Our data suggest that, similar to low-level visual features, high-level face representations in working memory are biased by the processing of related but task-irrelevant information.

Keywords Visual working memory · Distraction · Bias · Face perception

Introduction

Visual working memory (VWM) comprises the brief maintenance and manipulation of visual information. Visual perception and VWM work in tandem to construct a singular and comprehensible visual experience (Fischer & Whitney, 2014; Kiyonaga, Scimeca, Bliss, & Whitney, 2017). The reliance of VWM and perception on similar and overlapping neural resources (D'Esposito, 2007; D'Esposito & Postle, 2015; Fuster, 1997; Pasternak & Greenlee, 2005; Postle, 2006; Serences, 2016) highlights their interdependence (Awh & Jonides, 2001; Kiyonaga & Egner, 2013). Accordingly, previous research has shown that information retained in VWM

biases perceptual attention towards similar features in the external environment (Olivers, Peters, Houtkamp, & Roelfsema, 2011; Soto, Hodsoll, Rotshtein, & Humphreys, 2008), and conversely that perceptual information impacts VWM retention (Yoon, Curtis, & D'Esposito, 2006).

Perceptual interference can impact VWM by a general disruption of performance (Allen & Ueno, 2018; Bae & Luck, 2018; Clapp, Rubens, & Gazzaley, 2010; Magnussen & Greenlee, 1992; Magnussen, Greenlee, Asplund, & Dyrnes, 1991; Marini, Scott, Aron, & Ester, 2017; Yoon et al., 2006). A distractor presented during the maintenance period negatively impacts performance when retaining low-level features in VWM such as color (Nemes, Parry, Whitaker, & McKeefry, 2012; Nilsson & Nelson, 1981), spatial frequency (Bennett & Cortese, 1996; Magnussen et al., 1991; Nemes, Whitaker, Heron, & McKeefry, 2011), spatial location (Marini et al., 2017), or motion (Magnussen & Greenlee, 1992; McKeefry, Burton, & Vakrou, 2007; Pasternak & Zaksas, 2003). These negative consequences are often restricted to situations where the distractor and memoranda are from an overlapping feature-space (Magnussen & Greenlee, 1992, 1999; Magnussen et al., 1991). Effects of general working memory disruption have been shown using complex stimuli such as faces and scenes (Berry, Zanto, Rutman, Clapp, & Gazzaley, 2009; Bettencourt & Xu, 2016; Clapp & Gazzaley, 2012; Clapp et al., 2010; Clapp, Rubens, Sabharwal, & Gazzaley, 2011; Feredoes, Heinen, Weiskopf, Ruff, & Driver, 2011), and

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✉ Remington Mallett
remym@utexas.edu

1 Department of Psychology, University of Texas at Austin, Austin, TX, USA

2 Westwood High School, Austin, TX, USA

in some cases such consequences were dependent on target-distractor similarity (Jha, Fabian, & Aguirre, 2004; Jha & Kiyonaga, 2010; Yoon et al., 2006).

When perceptual distractors and memoranda are from the same low-level feature space, and within a certain range of similarity, memory responses show an attractive bias towards the distractor. This finding has been demonstrated with color (Nemes et al., 2012), orientation (Rademaker, Bloem, De Weerd, & Sack, 2015), spatial location (Van der Stigchel, Merten, Meeter, & Theeuwes, 2007), and spatial frequency (Dubé, Zhou, Kahana, & Sekuler, 2014; Huang & Sekuler, 2010b; Nemes et al., 2011). Recently, neuroimaging evidence suggests that neural VWM representations indeed shift towards the distractor in accordance with an attractive response bias (Lorenc, Sreenivasan, Nee, Vandenbroucke, & D'Esposito, 2018). To date, these perceptual biasing effects have not been tested using complex stimuli, which can offer insight into how these effects might apply to VWM in a more naturalistic setting.

To address this gap in the literature, we had participants remember faces under different conditions of distraction. Target and distractor faces were drawn from a continuous face space made of 80 computer-generated faces that varied continuously along the dimensions of age and sex (Lorenc, Pratte, Angeloni, & Tong, 2014). A delayed-estimation task with a method of adjustment response was used to quantify the accuracy of memory judgments. In three experiments, participants retained a single memory item while a task-irrelevant visual distractor was presented during maintenance. The three experiments varied only in their distance between the memory target and distractor in feature space (from 45° up to 135°). We predicted that responses would be biased towards the distractor, because this would be consistent with findings from similar paradigms that use low-level visual features as memoranda (e.g., Rademaker et al., 2015). The goals of this research were to relate the consequences of distraction on complex memoranda to findings for low-level stimuli, and to add to the broader consensus on the bidirectional relationship between perception and working memory.

Materials and methods

Participants

Participants were recruited from the undergraduate student body of the University of Texas at Austin through the SONA system provided by the Department of Psychology. Ninety adults participated in total (30 in each of three experiments; age range 18–22 years, 60 females). All experiments lasted approximately 60 min, and participants were compensated with course credit for their participation. Written informed consent was obtained in a manner approved by the University of Texas Institutional Review Board.

Stimuli

Stimuli were identical for all experiments. Memory targets were selected at random from a continuous face space consisting of 80 computer-generated faces (Lorenc et al., 2014; Fig. 1). As there were 80 unique faces in the continuous space, all distances were converted to a 360° space for interpretability (distance between two faces = 4.5°). The three-dimensional rendered faces were gray-scaled and varied continuously along the dimensions of age and sex. Stimuli were presented on a 21.5-in. iMac using PsychoPy (Peirce, 2007). Stimuli were presented on a gray background, and all text and fixation points were white.

Procedure

The procedure was identical for all experiments except for the distance between the memory target and distractor (Fig. 2A). Participants performed a delayed-estimation task with a method of adjustment response. Each trial began with a fixation cross (500 ms, 0.5° radius) followed by a centrally presented memory target (1,000 ms, 5° radius). Participants were instructed to remember the memory target as precisely as possible over the remainder of the trial. Stimulus presentation was followed by a delay period with a central fixation dot (3,000 ms, 0.05° radius). In the middle of the delay, a task-irrelevant distractor face was presented (1,000 ms, 5° radius) in the same spatial location as the memory target. The distractor face was clockwise (50% of trials) or counterclockwise of the memory target by approximately 45° (9–11 faces, uniformly randomized) in Experiment 1, 67.5° (14–16 faces) in Experiment 2, and 135° (29–31 faces) in Experiment 3. During training, participants were instructed to ignore the task-irrelevant distractor face while maintaining fixation. They were not informed of any relationship between the distractor and the memory target. Following the delay, participants selected the memory target from a continuous wheel using a computer mouse (≤ 30 s). The probe stage began with the computer cursor positioned centrally, and a dark gray wheel was presented (6.5° radius, 3° thickness) surrounding a face that morphed continuously (across all 80 faces of the face space) as the cursor moved around the wheel. The orientation of the face space was rotated randomly along the wheel every trial, and a face was not presented centrally until the cursor made contact with the wheel. Following response via mouse click, participants were provided feedback with a green indicator of the correct location of the memory target on the probe wheel (500 ms). Trials were separated with a 1,000-ms blank intertrial-interval (ITI). Each participant completed a single training run and then eight experimental runs of 24 trials each.
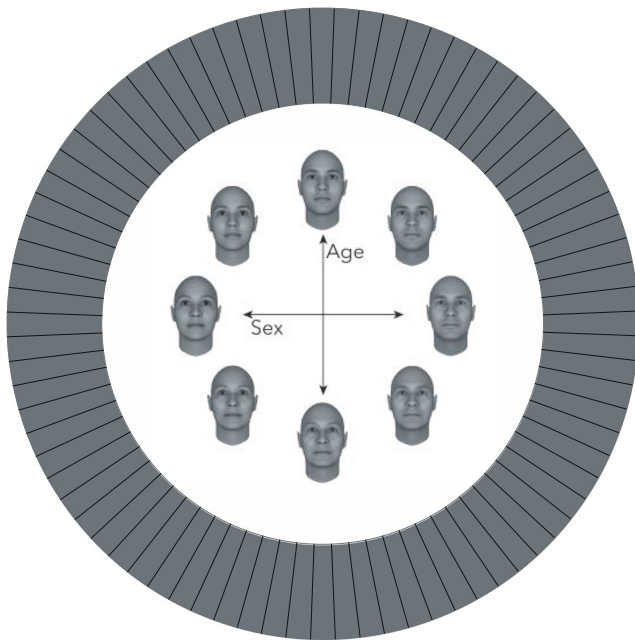
Fig. 1 Stimulus face space. Stimuli were 80 computer-generated faces that varied along dimensions of age and sex. Eighty slices around the wheel provide visualization of how much circular space each face occupied, and were not present during the experiment

Analysis

Each trial's error was calculated as the difference in degrees in the continuous face space between the response and the target. To quantify bias for each trial, we extracted the absolute response error in degrees, and assigned it a positive sign if the error was in the same direction as the distractor, and a negative sign otherwise. Therefore, a positive value indicates an

attractive bias (i.e., a response *towards* the distractor), and a negative value represents a repulsive bias (i.e., a response *away* from the distractor). In all experiments, this bias metric inherently collapses across clockwise and counterclockwise distractors. When evaluating whether a response bias was present, we performed a one-sample t-test against zero, where each participant contributed a single bias metric. To compare absolute response errors and biases across experiments, we performed between-subjects ANOVAs using the Pingouin Python package (Vallat, 2018). All statistical tests were two-tailed, and effect size d_z was calculated for all one-sample tests (Cumming, 2013). For each experiment, we removed outliers whose response biases across all trials were beyond 1.5 standard deviations from the mean (Exp. 1: *N*=2, Exp. 2: *N*=5, Exp. 3: *N*=4) to account for "swapped' responses where participants might have responded to the probe by selecting the distractor. Trials with no response in the time provided were removed (Exp. 1: five trials, Exp. 2: two trials, Exp. 3: no trials). All in-text descriptive statistics are reported as mean and standard deviation.

Results

Mean absolute response error was similar across experiments ($F_{(2,76)}$=0.6, *p*=0.55) with 29.3 ± 9° in Experiment 1, 28.4 ± 8° in Experiment 2, and 31.1 ± 11° in Experiment 3 (Fig. 2B). In Experiment 1, average response bias was reliably positive (*M*=1.34 ± 3.2°, $t_{(27)}$=2.23, *p*=0.034, d_z=0.42), reflecting a tendency of memory responses to be attracted towards the perceptual distractor (Fig. 3). This effect was replicated in
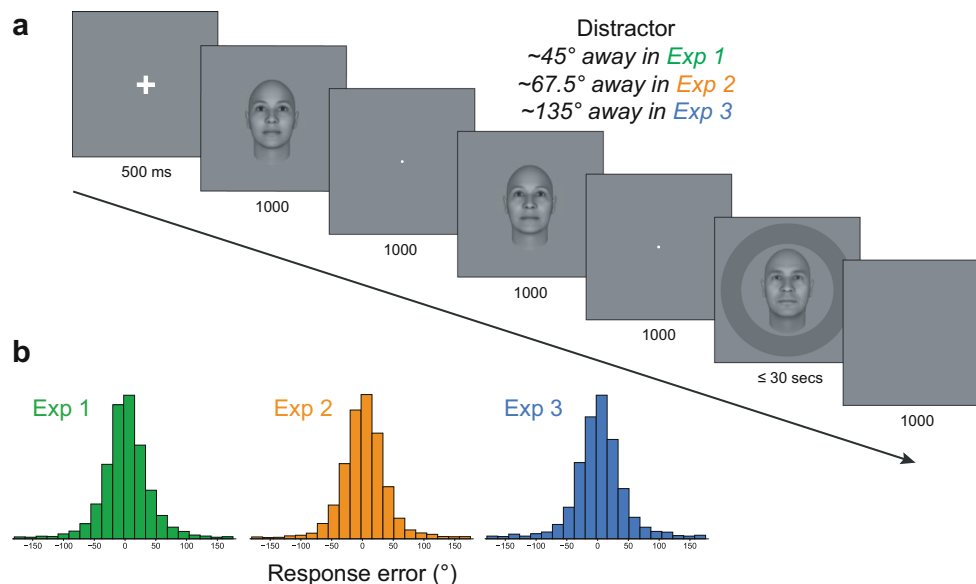

Fig. 2 (**A**) Experiment 1 task design. Participants encoded a single memory target and responded after a distractor-filled delay. Experiments differed only in the distance between target and distractor.

(**B**) Response error distributions. Response errors were normally distributed around the target and absolute response error was similar across all experiments

Experiment 2 in which there was an increase from 45° to 67.5° in the distance between memory target and distractor (M=1.62 ± 2.5°; $t_{(24)}$=3.31, p=0.003, d_z=0.66). Similarly, the effect was present when the target-distractor distance increased to 135° (M=1.71 ± 2.1°; $t_{(25)}$=4.12, p<0.001, d_z=0.81). While effect size increased with distractor distance, the magnitude of the bias effect did not differ across experiments ($F_{(2,76)}$=0.1, p=0.87).

Discussion

In three experiments, we tested the hypothesis that perceptual distraction presented during the delay of a visual working memory (VWM) task biases memory for faces. We found this to be the case across all experiments (total N=90). Our finding that working memories of complex stimuli are biased towards the perceptual distractor is consistent with previous results with low-level features as memoranda (Dubé et al., 2014; Huang & Sekuler, 2010a; Nemes et al., 2012, 2011; Rademaker et al., 2015; Van der Stigchel et al., 2007). Previous serial dependence research suggests that face perception is influenced by recently viewed faces (Liberman, Fischer, & Whitney, 2014; Taubert, Alais, & Burr, 2016). Here we show the reverse, that perceived faces impact recently encoded working memories of faces.
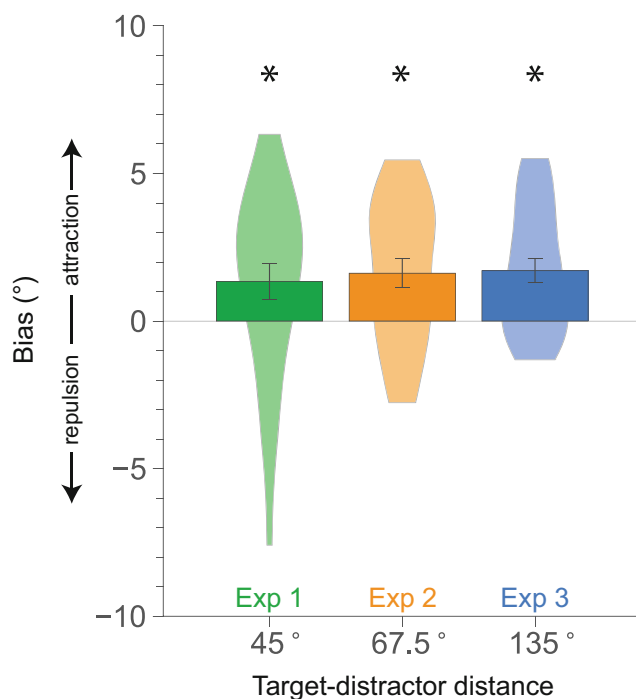

Fig. 3 Bias results from each experiment. Responses were similarly biased towards perceptual distractors across all experiments. The bias metric represents combined bias across all trials within each experiment. (error bars represent SEM; violin plots show density of individual participant data points; *p<.05)

Our findings of VWM response bias towards a perceptual distractor that is matched in feature space replicate previous findings that used color (Nemes et al., 2012), orientation (Rademaker et al., 2015), spatial location (Van der Stigchel et al., 2007), or spatial frequency (Dubé et al., 2014; Huang & Sekuler, 2010b; Nemes et al., 2011). Thus, our finding that this effect generalizes to complex stimuli like faces suggests that these stimuli share similar representational properties as basic features in VWM. It is possible that our observed bias resulted from low-level features that varied across the face stimulus set. However, this is unlikely given that facial recognition is frequently characterized as a holistic process, in that there is a tendency to perceive faces as an integrated whole rather than a composite of individual features (Farah, Wilson, Drain, & Tanaka, 1998; Taubert, Apthorp, Aagten-Murphy, & Alais, 2011). Regardless of whether the attractive bias we found across all experiments resulted from basic features or complex representations, the influence of perceived faces on memorized faces is consistent with the sensory recruitment account of VWM where perceptual resources are recruited for VWM storage (D'Esposito, 2007; D'Esposito & Postle, 2015; Fuster, 1997; Pasternak & Greenlee, 2005; Postle, 2006; Serences, 2016).

We found no effect of target-distractor distance on the magnitude or direction of working memory biases. Previous work has shown that increasing target-distractor distance increased memory bias (Rademaker et al., 2015); however, this was tested within target-distractor distances all below 45°, which was the lowest target-distractor distance in the current study. In previous work investigating the biasing effects between multiple VWM representations, the attractive/repulsive biasing effects are largely dependent on target-distractor distance (Bae & Luck, 2017; Myers, Chekroud, Stokes, & Nobre, 2018). Biasing complex stimuli such as faces might be weaker than the biasing of low-level visual features. Furthermore, the "distance" between targets and distractors might be more ambiguous because these stimuli vary across more than one dimension, unlike the typical unidimensional and continuous feature space of low-level stimuli. Additionally, some categorical and/or verbal recoding (Lewis-Peacock, Drysdale, & Postle, 2015) of the remembered faces might have occurred (Smyth, Hay, Hitch, & Horton, 2005), possibly preventing the subtle differences in bias as a function of distance. Notably, the similarity in bias across target-distractor distances provides further support that our results are unlikely to have resulted from "swapped" representations of target and distractor.

Our current design is unable to rule out the possibility of categorical recoding along the dimensions of age and sex (e.g., "old-ness" or "male-ness"). Indeed, this is also the case for similar experiments using low-level features. Even low-level features are recoded into categorical representations during working memory tasks (Bae, Olkkonen, Allred, & Flombaum, 2015; Hardman, Vergauwe, & Ricker, 2017). Furthermore, in another

situation where memory and perception interact, categorical verbal information in working memory can bias visual attention (Mannan, Kennard, Potter, Pan, & Soto, 2010; Soto & Humphreys, 2007; Soto, Rotshtein, Hodsoll, Mevorach, & Humphreys, 2012). Together, this suggests that if individual faces were recoded into categorical and/or verbal representations, we might still have detected these biasing effects. Note that participants were never explicitly informed about the two dimensions of age and sex that differed within the face space, which makes categorical recoding less likely. Future work using either neuroimaging or tasks that prevent verbal rehearsal (e.g., articulatory suppression) might help to determine how recoding influences biasing.

Face perception – like low-level features – is susceptible to visual adaptation, or "after-effects" (Jeffery & Rhodes, 2011; Strobach & Carbon, 2013; Webster & MacLeod, 2011). After-effects alter perception of images based on recent encoding of related material. As with low-level features, perception of faces can influence processing such that perception is biased away from the initially encoded face (e.g., adaptation to a male face resulting in a female bias; Webster, Kaping, Mizokami, & Duhamel, 2004). These effects have been found in face perception for both age (Schweinberger et al., 2010) and sex (Webster et al., 2004). After encoding the target face in the current experiments, perception of the distractor face might have been biased away from the target as a result of face-adaptation effects. Such a perceptual effect (either attraction or repulsion) might have influenced our results, but because the attractive biases we found were markedly smaller than the actual distance between target and distractor, we are unable to determine exactly how the distractor face was perceived.

Neuroimaging work has proposed a variety of neural mechanisms supporting maintenance during distraction periods of a VWM task. Proposals range across active maintenance in early visual (Lorenc et al., 2018) or parietal (Bettencourt & Xu, 2016; Lorenc et al., 2018) regions, activity-silent mechanisms (Lewis-Peacock, Drysdale, Oberauer, & Postle, 2012), connectivity between frontal and occipital regions (Clapp et al., 2010), or systematically modulated activity patterns (Derrfuss, Ekman, Hanke, Tittgemeyer, & Fiebach, 2017; van Loon, Olmos-Solis, Fahrenfort, & Olivers, 2018). Recently, Lorenc et al. (2018) showed that a perceptual distractor presented during a memory delay exerted an attractive bias on both behavioral responses and the neural representation in early visual areas. This suggests that the attractive biasing effects that arise in behavior correspond with active neural maintenance, yet the influence of neural overlap between target and distractor representations is still an open question.

As a final note, our use of faces as memoranda aids in the ecological validity of these results (Leopold & Rhodes, 2010). The biases demonstrated here in VWM might be applicable to important issues such as eyewitness testimony. Eyewitness testimony – primarily studied in the context of episodic memory (Chan, Thomas, & Bulevich, 2009; Thomas, Bulevich, & Chan, 2010) – is vulnerable to interference and misinformation (Butler & Loftus, 2018; Echterhoff, Hirst, & Hussy, 2005), specifically during suspect lineups. Suspect lineups require witnesses to choose a target face from a series of simultaneously or sequentially presented faces with similar critical features (Huff & Umanath, 2018). Our findings of perceptual distraction suggest that working memory may play a role in these decisions and impact the reliability of eyewitness testimony.

In summary, the current study contributes to a growing literature consensus that VWM representations are biased by distractors that vary along a goal-relevant feature dimension, and more generally that VWM and perception systematically influence each other. Our findings using a stimulus set that varies along complex feature dimensions suggests that the biasing effects of distractors on memories is a general characteristic of VWM that affects representations beyond those of low-level features.

Open practices statement All data, code, and stimuli are available on the OSF project site at https://osf.io/8zsrx/. None of the experiments were preregistered.

Author contributions RM, AM, and JLP conceived and designed the study and wrote the paper. RM and AM collected and analyzed data.

Compliance with ethical standards

Conflict of interest statement The authors declare no potential conflicts of interest.

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