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The fidelity of visual memory for faces and non-face objects

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ABSTRACT

The fidelity of visual working memory was assessed for faces and non-face objects. In two experiments, four levels of memory load (1, 2, 3, or 4 items) were combined with four perceptual distances between probe and study items, with maximum item confusability occurring for the minimum memory load. Under these conditions, recognition memory for multiple faces exceeded that of a single face. This result was primarily due to the higher false alarm rates for faces than non-face objects, even though the two classes of stimuli had been matched for perceptual discriminability. Control experiments revealed that this counterintuitive result emerged only for old–new recognition choices based on near-threshold image differences. For non-face objects, instead, recognition performance decreased with increasing memory load. It is speculated that the low memorial discriminability of the transient properties of a face may serve the purpose of enhancing recognition at the individual-exemplar level.

1. Introduction

Visual working memory (WM) provides temporary storage and manipulation of task-relevant information in cognitive processes such as perception (Simons & Rensink, 2005), attention (Awh & Jonides, 2001), and visual search (Emrich, Al-Aidroos, Pratt, & Ferber, 2010). WM maintains representations in an active and accessible state, but it has a limited capacity (Cowan, 2006).

The fidelity with which visual information can be maintained in WM depends on several factors. Large-scale or holistic information is extracted over a very short time, whereas the consolidation of this information, with the extraction of further details, requires longer presentation times (Hollingworth & Henderson, 2002; Melcher, 2001, 2006). The precision with which items are stored in WM is affected not only by *encoding time* but also by *set size*. With the increase of set size, less memory resources are allocated to each item and the precision with which items are stored in WM decreases (Alvarez & Cavanagh, 2004; Bays, Catalao, & Husain, 2009; Bays & Husain, 2008; Bays, Wu, & Husain, 2011; Brady, Konkle, & Alvarez, 2011; Wilken & Ma, 2004). The fidelity of WM also depends on *task demands*. Within a change-blindness paradigm, for example, the probability of a correct change detection is higher for the objects of central interest in the visual scene (Rensink, O'Regan, & Clark, 1997). Interestingly, the fidelity of WM is also influenced by *domain-specific expertise*. Wagar and Dixon (2005) showed that the properties of the information stored in WM depend on previous experience requiring the repeated categorization of the target objects into different families. In their study, a categorization learning phase improved the fidelity of WM for features diagnostic of category membership and *impaired* WM performance for non-diagnostic features.

The findings of Wagar and Dixon (2005) are consistent with recent studies suggesting that learning to categorize objects causes (1) an increase of perceptual discriminability along the dimensions relevant to the learned categories ("acquired distinctiveness"), and (2) a decrease in discriminability along the irrelevant dimensions ("acquired equivalence"). Goldstone and colleagues have proposed that "acquired distinctiveness" and "acquired equivalence" occur under both explicitly reinforced (i.e., supervised) and incidental (i.e., unsupervised) category acquisition (Gureckis & Goldstone, 2008). Many studies have provided empirical support for acquired distinctiveness (Goldstone & Steyvers, 2001; Notman, Sowden, & Özgen, 2005; Op de Beeck, Wagemans, & Vogels, 2003; Özgen & Davies, 2002), but empirical evidence in support to acquire equivalence is more elusive (e.g., Folstein, Palmeri, & Gauthier, 2012).

Here I propose that "acquired distinctiveness" and "acquired equivalence" modulate not only perceptual expertise, but also WM recognition. For a WM task, "acquired equivalence" translates into low-fidelity maintenance of transient and non-diagnostic features. The present experiments study this phenomenon for objects of expertise and objects of non-expertise.

1.1. "Acquired equivalence" in working memory

Based on the empirical findings described in the previous section, it is here proposed that "acquired distinctiveness" and "acquired

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equivalence" modulate the fidelity of the of the representations held in WM whenever experience induces a subordinate-shift in which objects are identified at a subordinate level rather than at the basic-level of categorization (Gauthier & Tarr, 1997; Johnson & Mervis, 1997; McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011; Nishimura & Maurer, 2008; Scott, Tanaka, Sheinberg, & Curran, 2006; Tanaka, Curran, & Sheinberg, 2005; Tanaka & Taylor, 1991). I propose that (1) perceptual dimensions that are relevant for identification at the individual level may receive a stronger memorial representation for objects of expertise than non-expertise ("acquired distinctiveness"), and (2) within-category image transformations that are irrelevant for identification at the individual level may manifest a lower memorial discriminability (i.e., may be represented with lower fidelity in WM) for objects of expertise than non-expertise ("acquired equivalence").

Face identity recognition always requires the selection of the invariant aspects that underlie face identity from the transient features generated by speech production, facial expression, and variations of the viewing conditions. Therefore, "acquired equivalence" may be especially important for faces, also considering that recognition at the individual exemplar is more important for faces than objects (Kanwisher, 2000).[1]

Previous work has shown a WM recognition advantage for faces over objects. For example, Curby and Gauthier (2007) showed that more faces can be stored in WM than other complex objects. Instead, the present data will show that faces can be at a disadvantage with respect to non-face objects, if the WM task concerns the recognition of transient changes in appearance (i.e., subtle image variations) that preserve the identity of the study items.

1.2. Plan of the experiments

In a pretest participants completed a same-different simultaneous matching task to measure perceptual discriminability for pairs of faces or cars lying on six morphing continua. In Experiments 1 and 2, participants performed a delayed matching task (Fig. 1) with the stimuli generated from the morph continua analyzed in the pretest. In Experiments 3a and 3b the difficulty of stimulus discriminability was decreased, in order to facilitate recognition performance.

Four levels of memory load (1, 2, 3, or 4 items to be retained in memory) were combined with four distances between the probe and the study items. In "different" trials, the physical differences between the probe and the to-be-remembered items comprised (1) small or large within-category distances (20 and 40 morphing steps, respectively), and (2) small or large distances crossing the category boundary (60 and 80 morphing steps, respectively) — see Tables 1 and 2. For the present stimuli, a physical difference of 20 morph steps is near the perceptual threshold for discrimination and it corresponds to subtle changes in appearance that preserve the identity of the item.

The items used in each single trial of Experiments 1 and 2 were selected from one morphing continuum generated between two faces or two cars. Different morphing continua were used to generate the items employed in different trials (Fig. 2).

1.3. Hypotheses of the present study

Memory loads of 1 and 2 included small and large within-category distances between the memory probe and the study items; memory loads of 3 and 4 included small and large across-category distances between the memory probe and the study items (see Table 2). The focus of the present study is on the small within-category differences, which were matched for perceptual discrimination across faces and cars, for stimulus presentation durations of 1000 ms (see Pretest).

[1] The perceptual expertise at recognizing objects at a more specific categorical level than the "basic level" of categorization (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) has been referred to as "individuation training" by McGugin et al. (2011).

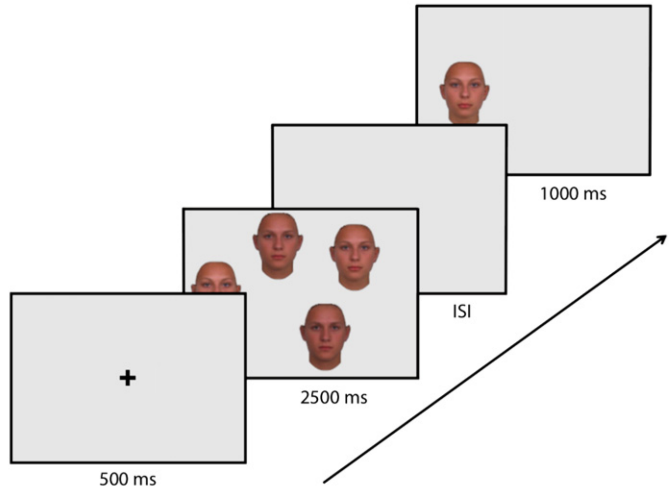

Fig. 1. An example trial from Experiments 1 and 2. After a fixation mark, a memory array of 1, 2, 3, or 4 items (faces, cat faces, or cars), a blank screen (ISI = 250, 750 ms, or 2500 ms), a memory probe, and another blank screen were presented sequentially. The participants reported whether the memory probe was the same as one of the items in the memory array.

"Acquired equivalence" predicts that subtle image differences, which are irrelevant for identification at the individual level, are represented in WM with lower fidelity for objects of expertise than non-expertise. In the present design, when the memory load was 1, the "new" probe differed from the study item only in terms of subtle image characteristics. Under these conditions, "acquired equivalence" predicts a higher false alarm rate for faces than cars.

The present design does not allow to test whether the hit rates are higher for faces than cars when the memory probe and the study items are separated by the category boundary. In fact, the memory loads 3 and 4 included both within-category and across-categories differences between the probe and the study items. Note, moreover, that the memory load of 2 included both small and large within-category differences between the probe and the study items. Under those conditions, "acquired equivalence" is not expected to occur.

In summary, when the memory load is larger than 1, there is no reason to expect that "acquired equivalence" and "acquired distinctiveness" may modulate in a different manner the hit rates and the false alarm rates of faces and cars. When the memory load is 1, instead, "acquired equivalence" predicts larger false alarm rates for faces than cars. As a consequence, in the present design the relationship between memory load and recognition accuracy, as assessed by d', is expected to be qualitatively different for the two classes of stimuli.

2. Experiment 1

Recognition accuracy for morphed Caucasian faces and cars was measured as the perceptual distance between the probe and the study items, the memory load, and the ISI were manipulated. The experiment was preceded by a pretest of the materials used in the old–new recognition task.

Table 1
Morph steps in the continuum between the memory probe and each item of the memory array in Experiments 1 and 2.

Memory load	Old trials				New trials			
1	0				20			
2	0	20			20	40		
3	0	20	40		20	40	60	
4	0	20	40	60	20	40	60	80