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S. MARTINEZ-CONDE

*Department of Neurobiology, Barrow Neurological Institute, Phoenix,
AZ 85013, USA*

S.L. MACKNIK

*Departments of Neurosurgery and Neurobiology, Barrow Neurological Institute, Phoenix,
AZ 85013, USA*

L.M. MARTINEZ

*Departamento de Medicina, Faculdade de Ciencias da Saúde, Campus de Oza, Universidade da Coruña,
15006, A Coruña, Spain*

J.-M. ALONSO

Department of Biological Sciences, State University of New York – Optometry, New York, NY 10036, USA

P.U. TSE

Department of Psychological and Brain Sciences, Dartmouth College, Hanover, NH 03755, USA



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The role of familiarity in the recognition of static and dynamic objects

Isabelle Bühlhoff^{1,*} and Fiona N. Newell²

¹Max-Planck-Institut für biologische Kybernetik, Spemannstrasse 38, D 72076 Tübingen, Germany

²Department of Psychology, Trinity College, University of Dublin, Aras an Phiarsaigh, Dublin 2, Ireland

Abstract: Although the perception of our world is experienced as effortless, the processes that underlie object recognition in the brain are often difficult to determine. In this chapter, we review the effects of familiarity on the recognition of moving or static objects. In particular, we concentrate on exemplar-level stimuli such as walking humans, unfamiliar objects and faces. We found that the perception of these objects can be affected by their familiarity; for example the learned view of an object or the learned dynamic pattern can influence object perception. Deviations in the viewpoint from the familiar viewpoint, or changes in the temporal pattern of the objects can result in some reduction of efficiency in the perception of the object. Furthermore, more efficient sex categorization and crossmodal matching were found for familiar than for unfamiliar faces. In sum, we find that our perceptual system is organized around familiar events and that perception is most efficient with these learned events.

Keywords: familiarity; faces; dynamic objects; haptic recognition; categorical perception; biological motion

Introduction

The difficulty of object recognition is often not appreciated because our phenomenal experience is that the visual system is very efficient at this task. Fig. 1 is an illustration of some of the problems that the visual system encounters in everyday recognition. It has to achieve what is known as object constancy. Specifically, the system must be able to recognize a particular chair, despite variations in illumination, size, orientation, and shape. Even though shape is the basis of object recognition and its perception has been investigated for decades, there is still an ongoing debate about how objects

are represented in the brain (see e.g., Newell et al., 2005).

One important question about object recognition is how various visual cues, such as motion, disparity, texture, color, and shading, are integrated into a unique object percept. In numerous studies, the role of these cues and their interplay has been investigated thoroughly (for reviews, see Landy et al., 1995; Ernst and Bühlhoff, 2004 among many others). Some researchers have reported rather unexpected interactions between visual cues. For example, it has recently been shown that color can influence size perception, in that objects with more saturated colors appear larger than objects with less saturated colors (Ling and Hurlbert, 2004). Other studies have found that shadows can help disambiguate shape perception when shape information is ambiguous (e.g., Bühlhoff et al., 1994; Bühlhoff and Kersten, in prep). Thus, it seems clear from

*Corresponding author. Tel.: +49-7071-601611;
Fax: +49-7071-601616; E-mail: isabelle.buehlhoff@tuebingen.mpg.de

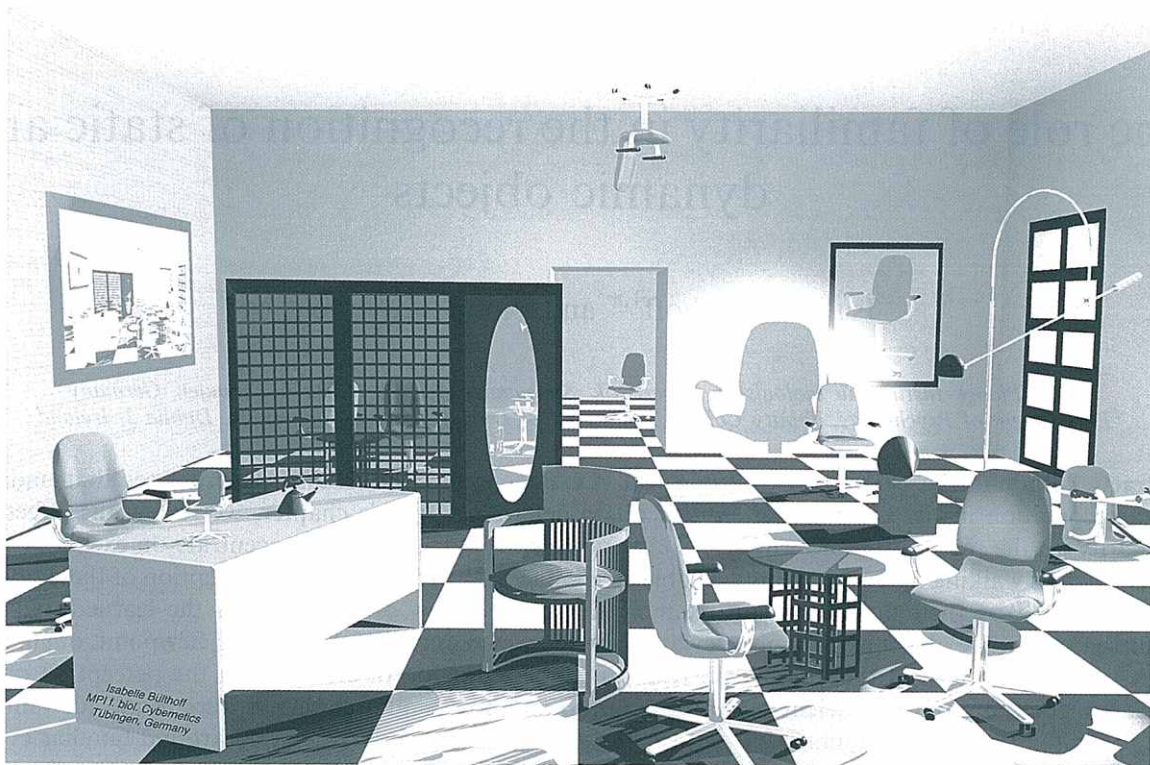


Fig. 1. This image of a complex scene illustrates some of the problems encountered in visual processing when recognizing objects. For example, we can recognize all office chairs in the scene, despite drastic variations in appearance due to different conditions of viewing (e.g., occlusion, orientation, size, location, and illumination).

these studies that distinct visual cues are important in building a robust representation of an object in memory in order to achieve object constancy and efficient object recognition.

The problem of achieving object constancy, however, is further complicated by the fact that most objects can move around the environment. As such, static object information and all associated cues, such as shading and disparity information, change from one moment to the next as the object moves. Consequently, the visual system often has to achieve object constancy despite large changes in the spatial properties of the object.

The purpose of this review is to highlight some of the everyday object recognition tasks the human brain has to solve and to review studies that have helped us better understand how this is achieved. We have decided, in particular, to limit the review to two main tasks: how moving objects are recognized and how very similar exemplar objects, such

as static images of faces, are differentiated. We believe that these types of tasks highlight the complexity and richness of object recognition in the human brain.

Recognizing moving objects

It is well known that dynamic cues can play an important role in object recognition. Humans and even animals can recognize animate objects not only on the basis of their static appearance but also from how they move (Johansson, 1973; Blake, 1993). We can even recognize such stimuli from dynamic information alone in the absence of clear spatial information (Johansson, 1973). Animate objects represented only by bright spots located at their main joints often cannot be identified in static images, but are easily recognized when a series of images is shown in a *biological motion* sequence.

Influence of familiarity on perception of biological motion

In our study (Bülthoff et al., 1997, 1998), point-light walkers similar to those used by Johansson (except for the presence of depth information, see Fig. 2) were employed to test whether the viewpoint-dependent recognition framework (for review, see Bülthoff et al., 1995) could also account for recognition of biological motion. In the viewpoint-dependent recognition framework, static objects are represented as a collection of two-dimensional (2D) views. This framework can be extended to dynamic objects by storing 2D motion traces that are projections of the three-dimensional (3D) trajectories of feature points onto the viewing plane. Dynamic 3D objects are then represented as a collection of several such 2D traces captured from various viewpoints.

If a view-dependent mechanism mediates the recognition of dynamic objects, the familiarity of a view should have a strong influence on recognition performance. That is, recognition should be easiest from viewing positions that have been experienced more often because participants are more likely to have stored internal traces of dynamic objects as seen from these positions. Another prediction is that modifying the depth structure of the stimuli should not affect recognition performance as long as the 2D traces remain unchanged.

All point-light stimuli were derived from one biological motion sequence showing a real human walking. The importance of view familiarity was

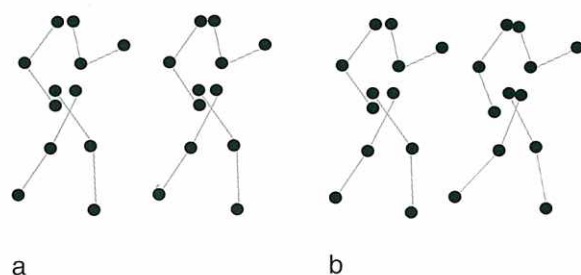


Fig. 2. Stereogram of undistorted (a) and depth-distorted (b) human walkers represented by dots only. Cross-fusers will notice that the 3D structure is severely distorted in (b) but not in (a). Connecting lines were absent in all experiments. Adapted with kind permission from Bülthoff et al. (1998).

investigated by measuring the recognition performance of participants viewing the same point-light walker from various viewpoints (Fig. 3). All stimuli were presented either with or without binocular disparity to investigate whether information about the depth structure of the stimuli affected recognition. Participants were asked to report if they recognized a meaningful moving object or saw only random moving points. The recognition rates for stimuli presented with or without binocular disparity indicate a strong viewpoint dependency (Fig. 4). Recognition performance was poor for top views where walking figures were recognized less often than when observed from viewpoints near the equator.

These results support the viewpoint-dependent recognition framework. As the framework predicts, participants' performance should be strongly tied to the familiarity of the viewpoint from which the walker is seen. Furthermore, the results suggest that participants' recognition performance was not based on the use of a viewpoint-invariant internal representation that could have been built during a lifetime of observing humans in motion. Adding depth information to the stimuli did not facilitate recognition. This result suggests that the internal representation used to recognize biological motion

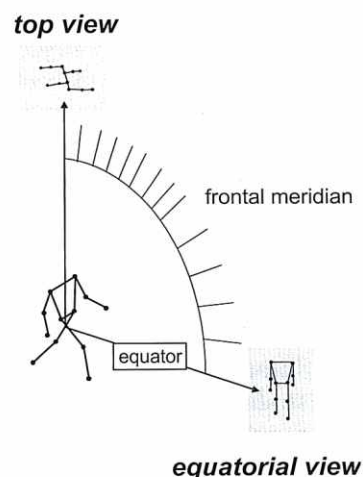


Fig. 3. Viewing positions of a point-light walker used to test view-dependent recognition. The bars along the frontal meridian indicate the viewing positions. The gray screens show the 2D projections of one frame of the animation for the top view and for the equatorial view.

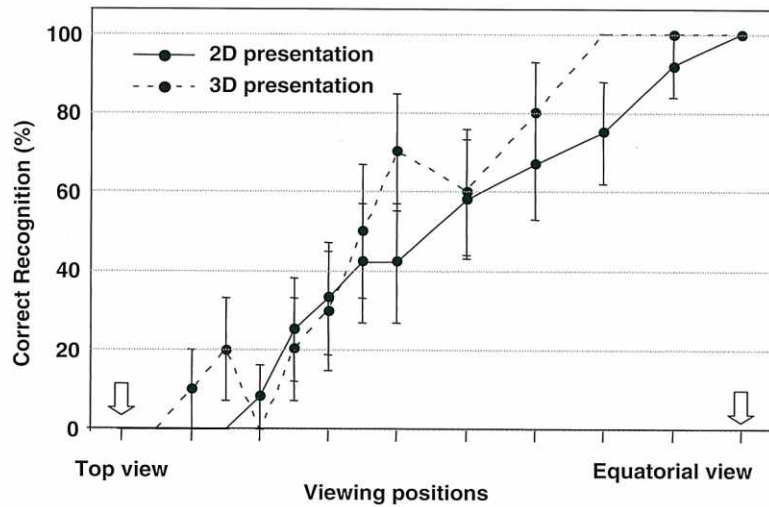


Fig. 4. Recognition performance of a point-light walker plotted as a function of viewpoint. Two-dimensional presentation: point-light displays presented without depth information. Three-dimensional presentation: point-light displays presented with depth information. Adapted with permission from Bühlhoff, I. and Bühlhoff, H.H. (2003).

is largely 2D, and that viewpoint familiarity is the primary determinant of the results.

As mentioned earlier, if object representations are largely 2D, then distorting the depth structure of the walker should not impair recognition as long as the 2D traces are left unchanged. Further experiments testing recognition of depth-distorted walkers (Fig. 2) supported this prediction. Because of their familiarity with the figure suggested by the 2D motion traces, participants perceived depth-distorted walkers as human walking figures; they did not seem aware that their 3D structures were not congruent with that of a human walker.

Spatiotemporal representations of familiar objects

Although studies of biological motion can reveal how dynamic information alone can affect perception, these studies do not make clear how dynamic information is integrated into an object percept when shape information is available. Some researchers argue that motion offers an alternative route to object perception but that this information is processed independently from shape perception (Kourtzi and Nakayama, 2002). On the other hand, recent studies have found that motion

can often disambiguate shape information when spatial information is reduced (Hill and Johnston, 2001), and that motion information is integrated into the identity of the object (Knappmeyer et al., 2003; Newell et al., 2004).

In a recent study, we have shown that the dynamic properties of an object are learned and integrated into the object percept along with its spatial properties (Newell et al., 2004). In our study, participants were first required to familiarize themselves with a set of novel objects, each with a distinct moving pattern. Thus, the dynamic and static information were both diagnostic of object identity. In our study, we were interested in ascertaining whether or not motion and shape would necessarily be integrated into a spatiotemporal representation of the object. The results suggested that this was indeed the case, but only for object motion that was intrinsic to the object itself. When the familiar intrinsic motion of an object was changed, object categorization performance was significantly reduced. However, manipulating the extrinsic motion information (i.e., the path that the object took in an environment) did not affect performance. More recently, we found that the motion of a novel object's parts as well as the whole object motion can prime the identity of a

static version of the object relative to a static view of the object (Setti and Newell, in prep). Taken together, these studies suggest that the familiar movement of an object can be integrated with spatial information into an object's representation in memory that allows for efficient recognition. Moreover, these and other studies on disparity, texture, and color information show that all available visual cues are useful for recognition and suggest that all are integrated in memory as part of an object's representation.

Recognizing static exemplar objects

We now want to turn to a class of stimuli for which the human observer is an expert in terms of shape and texture perception, namely faces. Faces have great social importance because facial information can indicate friend or foe and communicate the emotional state of the individual. Prosopagnosic patients, for example, suffer greatly in their social interactions because of their impaired ability to recognize familiar faces. Compared to many other object classes, faces are all very similar to each other; thus, they are a very homogeneous class. Differentiating one face from another consequently presents a difficult challenge to any perceptual system. Nonetheless, we seem to be able to make facial differentiations effortlessly and without obvious problems. Some theorists argue that efficient face recognition is achieved because the human brain has an innate propensity to process and recognize faces (Grill-Spector et al., 2004; Yovel and Kanwisher, 2004). In this view, faces are a special class of objects. Other researchers, however, have argued that faces are simply a class of object stimuli with which we have a lot of practice. In this view, the phenomena of face recognition are the product of a large accumulation of expertise with these stimuli (Diamond and Carey, 1986; Gauthier et al., 2000). Although this debate is ongoing, this review will not consider whether faces are special or not. Suffice it to say that they are important to our everyday social activities. Instead, our research has focused on the question of how the visual system differentiates between similar objects, such as faces, so that efficient recognition is achieved.

Perceiving familiar face categories

While some object categories are physically very different from each other, (e.g., cars and insects), others are very similar (e.g., male and female faces). Thus, the visual system has to categorize similar objects as the same and highlight differences between different category objects. Generally this is a relatively easy problem to solve because many object categories are intrinsically unique in terms of their spatial properties. However, for object classes that are highly similar, such as male and female faces, the problem becomes more difficult to solve. Recent studies have suggested that the visual system solves this problem through a process known as categorical perception (Harnad, 1987). Thus, objects within a category are perceived as more similar to each other than to objects belonging to another category even if the physical differences between them are equal. For experimental purposes, the hallmarks of categorical perception (CP) are twofold: a CP effect occurs when (1) a sharp change of response occurs at the subjective category boundary in a categorization task, and (2) pairs of stimuli are discriminated more accurately when they straddle the subjective category boundary than when both belong to the same category (even if the physical differences between the pairs are equal). In other words, in CP the peak in discrimination performance occurs at the category boundary defined by the categorization response function.

Recent studies using complex visual stimuli, such as faces, have suggested that CP occurs for categories such as facial expressions (Calder et al., 1996; de Gelder et al., 1997; Young et al., 1997), identity of familiar faces (Beale and Keil, 1995), and identity of familiar objects (Newell and Bühlhoff, 2002). There is, however, a suggestion in the literature that effects of categorical perception depend on the familiarity of the object stimuli. For example, some studies have shown that CP effects for unfamiliar or novel stimuli can emerge from short-term learning of category items (Goldstone, 1994; Livingston et al., 1998) and for unfamiliar stimuli, such as face stimuli, learned in the course of an experiment (Levin and Beale, 2000). We have previously reported that the perception of the sex of a face is

not automatic but is dependent on the familiarity of the face. In particular, face familiarity affects categorical perception thus allowing for better discrimination and categorization of the sex of faces (Bülthoff and Newell, 2004).

Male and female are well-known facial categories, and our ability to recognize the sex of an unfamiliar face is generally good (Bruce et al., 1993; Wild et al., 2000). Indeed, the well-known model by Bruce and Young (1986) for face processing proposes that the sex of a face can be derived whether the face is familiar or not (Bruce et al., 1987; see also le Gal and Bruce, 2002). Other studies have, however, challenged the notion that sex perception in faces is unrelated to the familiarity of the face (Goshen-Gottstein and Ganel, 2000; Baudoin and Tiberghien, 2002; Rossion, 2002) and argued that familiarity facilitates sex discrimination. In a previous study, we investigated the role of face familiarity on the emergence of CP for the sex of faces. If sex perception is related to facial identity then we expect that CP effects would emerge for familiar faces only. On the other hand, if the sex of a face is information unrelated to its identity, we expect that effects of CP would emerge for all faces, irrespective of familiarity.

A problem with studying sex perception in faces is that two faces differing in sex always differ in identity too; thus, identity is often a confounding variable in these studies. With present media technology and computational methods (e.g., Blanz and Vetter, 1999), one can create face images differing in sex information alone without changing identity. Using the algorithm of Blanz and Vetter (1999), we created sex continua in which the endpoint faces had different sexes but the same facial features. Each of these continua was based on one of six female faces. In each sex set, all features of the original face were transformed (masculinized) in 10% steps into the corresponding male face (for details see Bülthoff and Newell, 2004). Fig. 5 shows six original female faces and their computationally derived corresponding male faces and masculinized faces in-between in 20% steps. With these face stimuli, we could investigate whether the sex of a face is perceived categorically independent of the change of characteristic facial features related to identity.

In our initial experiments, all face stimuli were unfamiliar to the participants. Participants performed a categorization task and a discrimination task. In the categorization task, individual face stimuli were presented and the participant was required to categorize each as either male or female. The discrimination task in our studies typically consisted of a pair-wise face matching (i.e., same or different). The stimuli were presented in blocks according to facial identity in order to promote any existing effects of CP.

Typical categorization and discrimination results are shown in Fig. 6. Importantly, the shape of the categorization function is not step-like, so the first hallmark of CP was not observed. Participants could tell the sex of the endpoint faces, but there was no obvious consensus about the location of the subjective boundary between both sexes that would have been shown up by a step-like function. In the discrimination task, face pairs straddling the sex boundary were not significantly easier to discriminate than within-category pairs. Thus, the categorization and the discrimination results did not exhibit CP for sex in unfamiliar faces.

We expected that sex categories would be well-defined categories requiring no learning, but the results of our initial results suggested that this was not the case. So our next question was whether or not the perception of the sex of a face was dependent on the familiarity of that face.

In our subsequent experiments, participants were trained to categorize all face stimuli by their sex (see Goldstone, 1994; Goldstone et al., 2001 for similar procedures) prior to testing for CP. The training phase consisted of a sex categorization task in which participants were given feedback on the accuracy of their response on each trial and were required to reach a criterion performance before proceeding to the main experiment.

Typical response functions to our sex categorization and discrimination tasks are shown in Fig. 6. The subjective category boundary was very close to the physical sex boundary in the categorization task. The discrimination scores on the same/different task were converted to d' scores. Our statistical analyses revealed that discrimination performance for face pairs straddling the category boundary were significantly better than within-category pairs.

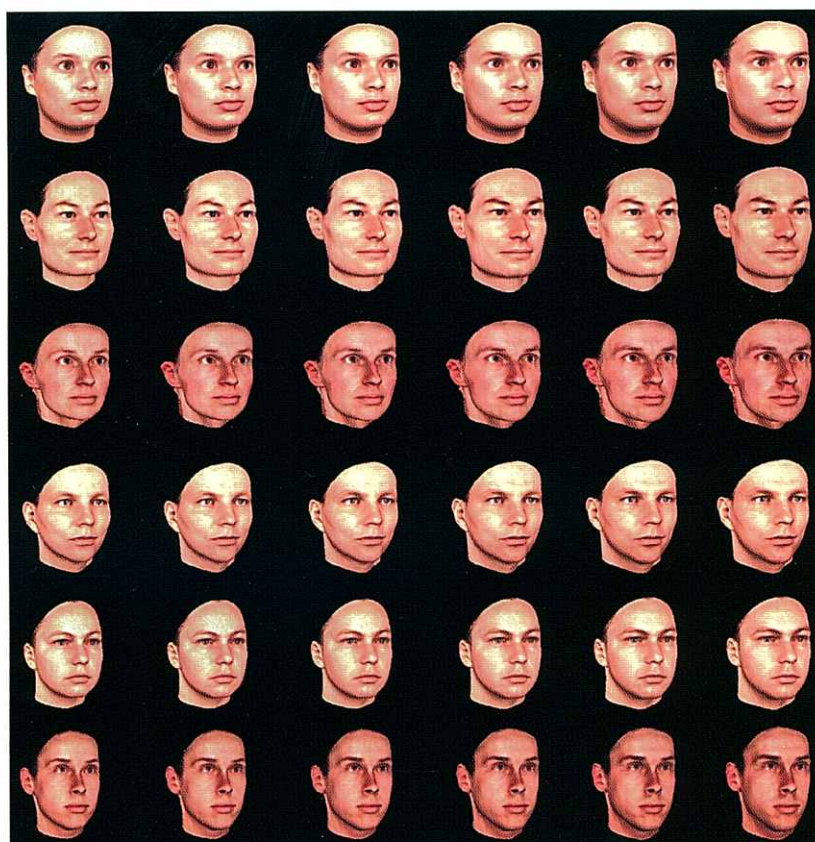


Fig. 5. Sex continua: in each row, the endpoint faces are of different sex but share the same facial features. All leftmost faces are original female faces, and all rightmost faces are computationally derived corresponding male faces. Morphs in-between are shown in 20% steps.

Therefore, our findings exhibited CP for sex after familiarization.

Our results indicate that sex information is available for CP, but only when the faces are familiar. Thus, despite the importance of face perception, sex information present in faces is not naturally perceived categorically. Our findings have implications for functional models of face processing that suggest two independent processing routes, one for facial expression and another for identity (Bruce and Young, 1986): we propose that sex perception is closely linked with the processing of facial identity.

Familiarity and crossmodal face perception

We have recently embarked on a project to investigate the role of familiarity in crossmodal face

perception. Our initial studies suggested that familiarity can also facilitate face perception across different modalities (Casey and Newell, 2005). We first investigated whether long-term familiarity has an effect on crossmodal face perception by testing participants' ability to recognize a mask of their own face via touch and vision (Fig. 7). Performance was better for visual self-recognition than for recognition via touch. Thus, despite a lifetime of experience with touching one's own face, a representation of the face is not available in tactile memory. In our subsequent experiments, we trained participants to recognize a set of previously unfamiliar faces via either touch or vision alone. We then conducted a crossmodal, face-matching study in which participants were required to match a face mask sampled with touch with a visual counterpart. Face pairs were either

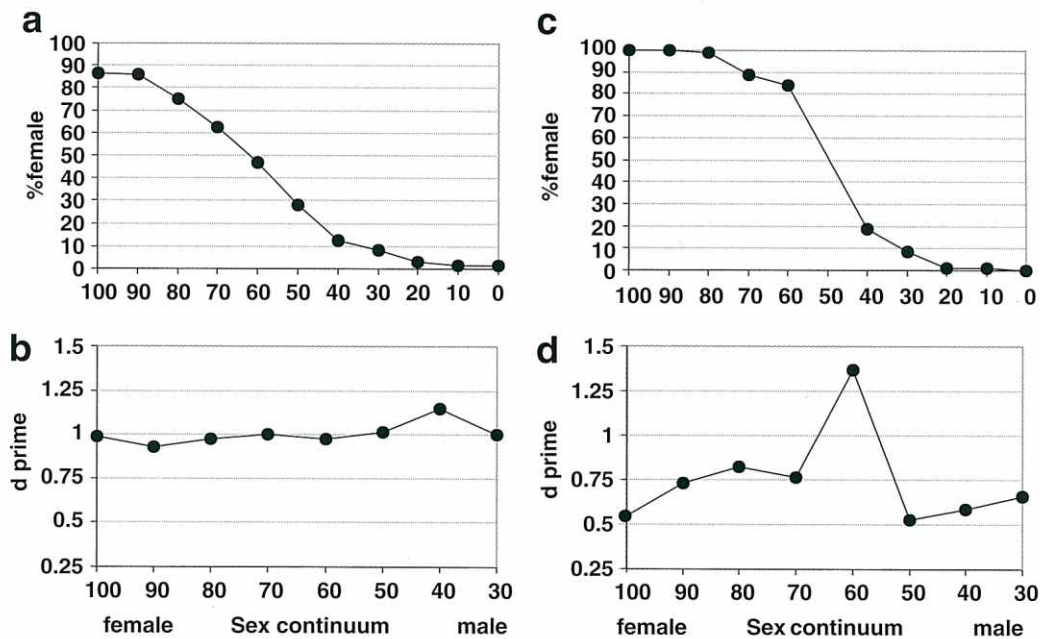


Fig. 6. (a) and (b) Categorization and discrimination performance for unfamiliar face continua. (c) and (d) Categorization and discrimination performance after training. (a) and (c) Mean frequency of "female" responses (%) in the categorization task as a function of the sex of the face stimuli. (b) and (d) Mean discrimination data (d') as a function of the sex of the face pairs. (b) and (d) Only the most female image of each pair is mentioned on the abscissa (i.e., "100" corresponds to the face pair 100%–70%, etc.). Adapted with kind permission from Bühlhoff & Newell (2004). <http://www.psypress.co.uk/journals.asp>.

familiarized or unfamiliar faces. We found that the matching performance for familiar faces was significantly better than performance for unfamiliar faces. Our findings suggest that familiarity with a face, irrespective of the modality through which it is encoded, benefits face perception by providing a robust representation of the spatial characteristics of that face in memory.

General discussion

Being familiar with objects or categories of objects can drastically change the way we perceive them. Many studies have provided evidence that familiarity evokes different perceptual processes for the purpose of recognition. Familiar views of novel objects are better recognized than less familiar views (e.g., Edelman and Bühlhoff, 1992). Furthermore, even very familiar objects are better recognized from more usual viewpoints than from unusual views (Palmer et al., 1981; Newell and Findlay,

1997), suggesting that representations of objects in memory are organized around the more commonly observed aspects of the objects in the environment. In this chapter, we reviewed studies that extend these original findings and reported that familiarity, in most circumstances, can benefit the perception of dynamic point-light displays, moving objects, the sex of faces, and face recognition across different modalities by allowing for better (i.e., faster and more accurate) recognition of these objects.

In the studies reviewed here, the stimuli and tasks were generally familiar to the participants. For example, judging the identity of a person by gait alone is a common task (such as when that person is far away) as is recognizing moving objects. We showed that untrained participants can easily recognize point-light walkers when those figures are shown from viewpoints that they have experienced with real people, but that they cannot identify these walkers from unfamiliar viewing positions (i.e., top views). When seen from unfamiliar viewpoints, moving point-light displays were perceived as

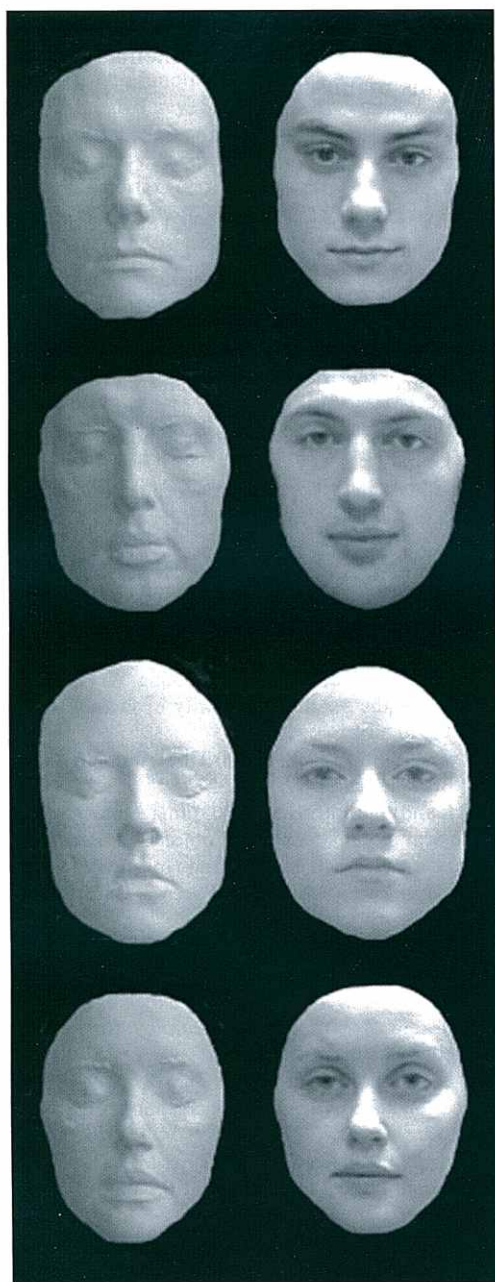


Fig. 7. An image of the face masks used in the crossmodal face recognition experiments. Images of the real faces are shown beside each face mask for illustrative purposes only.

random moving patterns and could not be identified. Furthermore, familiar dynamic patterns given by the 2D motion traces of the point-light displays

allowed participants to override any depth discrepancies. Participants perceived walking humans when they saw depth-distorted patterns that could not possibly represent normal walking humans. These findings suggest that the 2D projection of the dynamic pattern is primarily used to perceive biological motion. These results were discussed in view of the important question of 2D vs. 3D representations of objects in memory, but here we want to emphasize the influence of familiarity on recognition of familiar dynamic objects. Generally in the real world, the 2D pattern is sufficient for interpreting a perceptual scene; moreover, the 3D representation of that pattern is rarely distorted. Consequently, the observed effects are possibly the result of experience with familiar patterns that allow us to base our perception on assumptions built up during the course of one's lifetime (also referred to as "priors" in Bayes' theorem, 1764).

Similarly, we found that the recognition of novel objects was affected by the familiar motion of the object itself (e.g., whether it wobbled or tumbled) but not by its familiar path or route. The path of the object was useful for recognition when it was the only feature diagnostic of object identity, suggesting that although it was perceived it was not integrated into the object's representation in memory. If we think about moving objects in the real world, objects rarely move along a stereotyped route. Therefore, our results may simply reflect real-world perception where route information is not a familiar cue to object identity and is not integrated into the representation in memory.

Again, categorizing the sex of a face is a task we have done since birth. In the set of experiments reported here, we investigated how the sex of a face is perceived. Participants were confronted with the unusual task of classifying as male or female a set of highly similar faces that varied along the sex dimension only. We claim that evidence of CP emerges only after participants were familiarized with the set of faces and with the task. Our results suggest that our visual system, in the absence of training, would incorrectly treat such similar exemplars as slightly noisy versions of the same face; participants were unable to separate clearly the faces in two categories that would normally allow for effects of CP to emerge. Again, here we want to

point out the striking influence of familiarity on the perception of sex in faces.

Finally, although the recognition of other faces through touch is not a familiar task to most people, tactile perception of one's own face is a common event. For example, we often feel our own faces for the purposes of grooming, yet our studies showed that despite this experience, recognition of one's own face through touch is not as efficient as through vision. Taken together, these studies suggest that it is familiarity with the stimulus properties *as well as* the task that results in better performance. The benefits of familiarity, we would argue, are therefore likely to be task-specific.

In summary, familiarity with an object or event helps build a robust representation of that object in memory allowing for efficient recognition of objects on the basis of statistical likelihood of the appearance of that object in the natural environment. Some of our findings suggest that the benefit of familiarity with objects seems to be specific to the task at hand and does not generalize to different types of tasks. For example, despite a lifetime of experience with seeing and touching one's own face, only visual recognition of our own face was possible. Without direct investigation of the interplay between task specificity and familiarity, this remains purely speculative. However, several recent studies suggest that the neural coding of objects is influenced by the task, or response contingencies, in that these neurons adapt according to the rules of the task (Duncan, 2001; Freedman et al., 2001). Consequently, it is possible that familiarity is indeed dependent on the task, and that the familiar properties of an object that benefit recognition performance may not influence other types of tasks.

Abbreviations

CP	categorical perception
2D	two-dimensional
3D	three-dimensional

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