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Helping the Cognitive System Learn: Exaggerating Distinctiveness and Uniqueness

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SUMMARY

The caricature advantage demonstrates that performance is better when exaggerated stimuli are presented rather than a faithful image. This can be understood with respect to a theoretical framework in which caricaturing maximises the distinctiveness and thus minimises any perceptual or representational confusion. In this study we examine the possibility to harness caricatures to enhance learning. Thus, during learning the caricatures help the cognitive system pick up the unique and distinctive features of the learned material. This in turn helps to construct representations that correctly direct attention to the critical information. We trained 113 participants to identify aircraft across any orientation and found that the use of caricature is advantageous. However, the caricature advantage was most effective in complex learning where it is difficult to differentiate among different aircraft. Furthermore, the caricature advantage for subsequent recognition is attenuated when over-learning has been achieved. These results are discussed in terms of the learning situations in which caricatures can be most effective in enhancing learning. Copyright © 2007 John Wiley & Sons, Ltd.

To maximise the potential of learning one must consider the workings of the human cognitive system. Understanding and correctly tapping into the human cognitive mechanisms involved in learning should enable to construct more efficient learning (Dror, 2007; Dror, in press). By efficient learning we mean that maximum knowledge is learned and remembered with minimal time and cognitive investment. The complicated and tricky step is how to connect and translate our understanding of the cognitive system to practical implications in learning. In this paper we try to do just that; namely to take the 'caricature advantage' effect and see if and how it can be utilised to enhance learning.

Within the face processing literature, a phenomenon known as the 'caricature advantage' has emerged. This describes the situation in which the processing of a familiar face is achieved more quickly or more accurately when presented with a distorted image of the person than when viewing an accurate image (see Rhodes, 1996 for a review). On the face of it, the fact that performance is improved despite the presentation of an image that is no longer faithful would seem to be counter-intuitive, especially given evidence which suggests that a mere change in viewpoint or expression can adversely affect subsequent recognition performance (Bruce, 1982). Nevertheless, the effect remains strong, and is

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evident across a range of experimental paradigms. This is largely due to the fact that the caricatures are not random distortion, but systematic distortions aimed to increase and exaggerate the distinctiveness and uniqueness of each item.

The first demonstration that caricatures enhance processing was presented by Rhodes, Brennan, and Carey (1987). They found that caricatured images of familiar faces were recognised with equivalent accuracy but in significantly less time than undistorted versions of the same faces. This effect has since been replicated using both line quality images (Stevenage, 1995a) and images of photographic quality (Benson & Perrett, 1991). Subsequent studies have also revealed the benefit of caricatured images when presented with a face-name matching task (Rhodes, Byatt, Tremewan, & Kennedy, 1996), and a perceptual task such as creating a good likeness (Rhodes et al., 1987) or choosing the best likeness from an array of images (see Benson & Perrett, 1991, 1994). The caricature advantage has been explored in other domains (see, McCandliss, Fiez, Protopapas, Conway, & McClelland, 2002; McClelland, Fiez, & McCandliss, 2002).

The most often cited explanation for the caricature advantage is that caricatures emphasise the distinctiveness of a face and are thus processed with the same advantage that naturally distinctive faces are (Bartlett, Hurry, & Thorley, 1984; Light, Kayra-Stuart, & Hollander, 1979; Shepherd, Gibling, & Ellis, 1991; Valentine & Bruce, 1986a,1986b; Winograd, 1981). Consequently, when stimuli are difficult to discriminate (because of their homogeneity or their manner of presentation, see Ashworth & Dror, 2000), images that emphasise the differences between stimuli will be processed more easily than images which are undistorted. Valentine's (1991) multidimensional space (MDS) framework provides a useful way of conceptualising this explanation (see Byatt & Rhodes, 1998; Stevenage, 1995a).

Within Valentine's MDS, faces are encoded according to their properties along meaningful dimensions which describe the set of known faces and define the space. Under a norm-based model, faces are encoded relative to a norm and in terms of a set of norm-face deviation vectors along each of the dimensions of the space. In contrast, under an exemplar-based model, faces are encoded relative to one another, with similarity between exemplars represented as distance within the space. Both frameworks are similar in their prediction of the natural distribution of exemplars within the space. This, of course, is related to theories of the processes governing object recognition in general, and whether such processes are piecemeal, configural or holistic (e.g. Dror, Ivey, & Rogus, 1997; Martelli, Majaj, & Pelli, 2005; Smith & Dror, 2001) and whether they are orientation dependent or orientation independent (e.g. Ashworth & Dror, 2000).

Categorical perception further provides a theoretical framework for this phenomenon, but emphasises the processing of representations rather then their modifications. It occurs when previously confusable stimuli come to be seen as separable and identifiable. For instance, with experience, one can come to be able to distinguish between male and female chicks, or cancerous and non-cancerous cells (see Harnad, 1987) or between identical twin (Stevenage, 1998). Goldstone (1998) suggested that this perceptual reorganisation occurs either because we come to attend to the relevant dimensions for the discrimination task, or because we become more sensitive to the minute differences that distinguish the stimuli along the dimensions we were originally using (see Aha & Goldstone, 1990; Corneille, Goldstone, Queller, & Potter, 2006; Goldstone, Steyvers, & Rogosky, 2003). Further, Schyns and Rodet (1997) suggest that this categorical perception occurs because, with experience, we create the necessary dimensions that are required to perform the sorting task. One way of understanding caricature effects, then, is to presume that in caricaturing, the dimensions, or the differences along the dimensions are emphasised and magnified so

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that what ordinarily went unnoticed is now evident. In this sense, the mental representations of the stimuli remain relatively the same, but the manner in which the stimuli are perceived and processes are affected with the result that stimuli are easier to sort, label and differentiate from one another. In a sense, these two explanations suggest the advantage of using caricatures, however they emphasise different aspects of how this may occur, namely facilitation via modification of the underlying representations and facilitation via targeting and direction attention in the processing of the representations. These can be viewed as two sides of the same coin, as the attention is guided differently when caricature representations are used.

Caricature effects therefore may be utilised to enhance learning in a variety of complex domains, and especially in difficult stimuli and with novices. Examination of the literature with respect to these two points reveals a mixed picture. On one hand, Rhodes and McLean's (1990) demonstration of a caricature advantage when matching names with outline images of birds presented the expected caricature advantage for non-facial stimuli. In fact, this effect emerged only when the bird set being viewed was sufficiently homogeneous (passerines) and so sufficiently difficult to warrant the assistance. Put together with the use of ships or trees (Stevenage, 1995b) and when designing images for rapid communication (see Dwyer, 1967; Ryan & Schwartz, 1956) these results clearly indicate that caricature effects are not restricted to face stimuli.

While Rhodes and McLean (1990) found a caricature advantage in the speed of bird recognition, this was actually only evident when participants were proficient with the stimuli, thus with experts and not novices. In addition, data presented by Byatt and Rhodes (1998) which examine the magnitude of the caricature advantage for own- and other-race faces suggest that the magnitude of the caricature effect is no different for the two sets of stimuli even though participants presumably possess less expertise for the other-race faces. Again, the data relating to perceiver proficiency do not support the expectation that caricature effects would be greater for naïve perceivers and learning.

One way to reconcile these findings with the theoretical expectations may be to view the proficient 'experts' in the previous studies as being located partway along a learning curve whilst being some way short of an over-learning state. As such, caricatured images would still present the proficient 'expert' perceiver with a significant advantage. This, of course, introduces a host of assumptions concerning just how much training is necessary before one can be defined as an expert and, in this sense, the use of a paradigm which uses explicit training rather than examining the performance of readymade novices and experts may be valuable. The present experiment attends to exactly this issue.

The present study represents an examination of the extent of caricature effects throughout a training procedure which takes participants from a novice state to a state of over-learning. Non-facial stimuli, namely aircraft, are used as the stimuli, and were selected because participants will bring a limited and roughly equivalent amount of knowledge to the task. Consequently, the use of such stimuli enabled us to examine the effect of caricatures on learning, the development of expertise from a uniformly low (novice) baseline.

METHOD

Design

A three-way mixed factorial design was used in which stimulus similarity (homogeneous, heterogeneous) was manipulated within-subjects, while image type at study (enhanced,

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original) and image type at test (enhanced, original) were manipulated between-subjects. As such, all participants endeavoured to learn aircraft from a highly similar (homogeneous) group and a more distinctive (heterogeneous) group, but half studied enhanced images while the remainder studied original images. Within these groups, half were tested with the images they had studied and half were tested with images of the other form.

In addition, the viewpoint of the aircraft during the learning phase was varied such that half the participants studied images presented from a canonical viewpoint (with the nose pointing up, right, down or left) and the remainder studied images presented from four non-canonical viewpoints. This counterbalancing measure was included so that results could not be attributed to a specific set of training conditions.

Following a learning phase, participants completed an identification task. Speed of accurate identifications was recorded during both learning and subsequent testing phases and represented the dependent variable.

Materials

Stimuli were generated from a set of eight aircraft images. These eight images were divided into two groups of four aircraft on the basis of prior work, using a cluster analysis of similarity ratings to determine the level of inter-similarity between stimuli (see Ashworth & Dror, 2000). From this, a set of four aircraft was selected from different clusters and formed the heterogeneous stimulus set (Fishbed (Mig-21), Galab (G-4), Tomcat (F-14) and Farmer (Mig-19)). A set of four additional aircraft was selected from a single cluster, and formed the homogeneous stimulus set (Eagle (F-15), Hornet (F-18), Flanker (SU-27) and Fulcrum (Mig-29)) These eight aircraft are depicted in Figure 1 below.

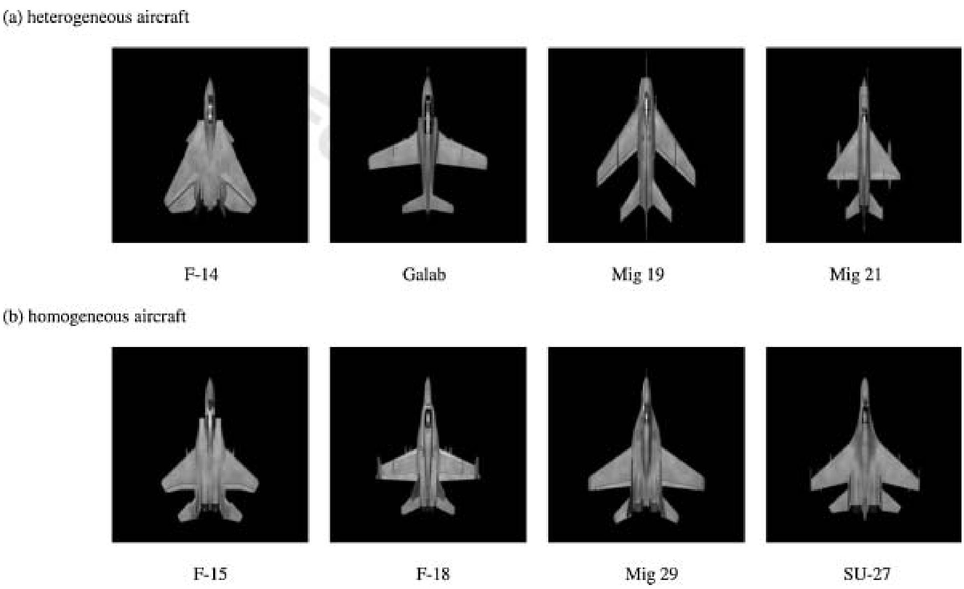

Figure 1. Examples of the four homogeneous and four heterogeneous aircraft stimuli presented as undistorted upright (0°) images

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The images of these eight aircraft were high resolution, grey-scale images depicting the aircraft from directly above. Accurate information about texture and shading was incorporated into the images and each aircraft image was scaled to be approximately 10 cm in length along the nose-to-tail axis.

Training stimuli
For each of the eight aircraft, a set of 16 images was generated. Four images depicted the aircraft at canonical orientations where the orientation of the aircraft matched the external orientation of the environment (0°, 90°, 180°, 270°). These images equated to the aircraft with its nose pointing up, right, down and left, respectively. A further set of four images was generated for each aircraft depicting non-canonical orientations set at 22.5° from the previous ones (22.5°, 112.5°, 202.5°, 292.5°).

The eight resultant images were then digitally morphed to generate a further eight enhanced images. Morphing was conducted using Morph 7.0 as follows: First, a set of 48 landmarks was manually located on each of the aircraft images within the homogeneous and heterogeneous aircraft sets. Using a technique which averages the x, y coordinates of each and every landmark across two comparable scaled images, a homogeneous composite was generated. This was achieved by creating a composite of the first pair of homogeneous aircraft, a second composite of the second pair of homogeneous aircraft and finally, a composite of these two composites. This resulted in a single image to which each original homogeneous aircraft had contributed equally. An average heterogeneous composite was generated in the same way to reflect each of the four heterogeneous aircraft equally.

The purpose of generating each composite was to provide a standard image against which each aircraft within the homogeneous and heterogeneous sets could be compared and enhanced. Hence, Morph was again used, and the 48 landmarks identified previously were located on each of the original images and the relevant composite image. Comparison of each original with the composite allowed an estimation of the deviation of x, y coordinates for corresponding landmarks. This deviation then described aspects of the aircraft which identified it and set it apart from the standard image. Exaggeration of these deviations by 25% resulted in an image which was more like the individual aircraft and less like the composite. In this way, distinctive or enhanced versions of each aircraft image were generated with respect to the appropriate homogeneous or heterogeneous group composites. The result was the generation of 16 images per aircraft 8 original (4 canonical, 4 non-canonical) and 8 enhanced (4 canonical, 4 non-canonical). These images formed the training set and participants were either trained with the original images or the enhanced ones.

Test stimuli
During test, to examine generalisability beyond those examples used during training, each of the eight aircraft was depicted at 64 orientations that increased in steps of 5.625° in the picture plane from a starting point of 0° (nose pointing up). These test orientations thus included the canonical (and non-canonical) views that participants had been trained on. In addition, each aircraft was depicted as an original or an enhanced image at each orientation. This resulted in 128 test images (64 original, 64 enhanced) for each aircraft. Again, participants were either tested with the original images or the enhanced ones.

Participants

A total of 113 participants took part in the present study and were randomly assigned to one of four conditions, with age and gender balanced across groups. Consequently, approximately a

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quarter of the participants studied and were tested with enhanced images; another quarter of the participants studied enhanced images and were tested with original ones; a quarter participants studied original images and were tested with enhanced ones and finally a quarter participants studied and were tested with original images.

All participants had normal, or corrected-to-normal vision, and had no prior contact with, or knowledge of, such aircraft stimuli. Participants were tested at the United States Air Force TRAIN Laboratory, Brooks, AFB, San Antonio, TX, and were paid for their time.

Procedure

The procedure developed in Ashworth and Dror (2000) was adopted here. The experiment was administered individually via an IBM-compatible computer with a high resolution 15″ colour monitor. Participants were seated at a distance of approximately 60 cm from the monitor within a three-sided testing cubicle. As such, they could not see the screens of any other participants within the room.

The experiment consisted of a two phase procedure which involved a learning phase followed by a test phase. Presentation of stimuli were blocked and counterbalanced so that half the participants completed learning and test phases for the heterogeneous stimuli first, and the remaining participants completed the learning and test phases for the homogeneous stimuli first. A break between the two blocks ensured a minimum of fatigue.

The learning phase consisted of six sequences of presentations. In the first sequence, each aircraft (homogeneous or heterogeneous, $n = 4$) was presented at each of 4 viewpoints a total of 10 times, making 160 presentations. The relevant printed name was presented alongside the aircraft image. Both image and name remained on screen for a period of 5 seconds, during which time the participant was instructed to study the image and try to remember the name in readiness for a subsequent test. After the image disappeared from view, the participant pressed one of four appropriately labelled keys on the keyboard to indicate the name of the aircraft just seen. This manual response ensured attention to the name, and mirrored the response required in the remainder of the experiment. Auditory feedback was provided in the form of a ‘beep’ if an incorrect key was pressed.

In the remaining five training sequences, participants were presented with images of each aircraft without the name. Again, a total of 160 presentations made up each training sequence and involved each aircraft ($n = 4$) being presented from 4 viewpoints a total of 10 times. Order of presentation was randomised across the five training sequences. The participant’s task was to press the appropriate key to indicate which aircraft they were looking at. Images remained in view until the participant had responded, and feedback was again given in the form of a beep to indicate an incorrect response. During these five training sequences, the speed and accuracy of participant response were recorded. Thus, learning consisted of 960 training examples for each set of aircraft, and a total of 1,920 all together.

Formal testing of aircraft learning was conducted on two occasions during the procedure. An early test was conducted half way through the procedure (after the third training sequence), and a later test was conducted at the end of the procedure (after the sixth and final training sequence). Testing took the form of the presentation of 320 randomised trials. The four aircraft were presented once at each of the 64 testing viewpoints (256 trials). In addition, 64 further trials involved the presentation of two previously unseen distractor aircraft. These were included to minimise the influence of guess responses. The participant’s task was to indicate which aircraft they were looking at by pressing one of the

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four known aircraft names, or a fifth key to indicate a 'new aircraft'. With 64 presentations of each known aircraft, and 64 presentations of one or other distractor, there was an equal number of responses assigned to each key. Participant accuracy and speed were recorded but, in contrast to the training sequences, no feedback was provided.

On completion of the second testing phase with the first set of stimuli, and following a short break, participants then completed the training and testing procedure with the second set of stimuli.

RESULTS

Speed and accuracy of aircraft identification were recorded for both homogeneous and heterogeneous stimulus sets across five training sequences, and two testing sequences. The error rates at each stage were very low (less than 3%) and were not analysed.

Performance during training

Data from the first training sequence, in which the name and image were both presented, were not included within the present analysis as performance here depended merely on the ability to read a name, wait for 5 seconds, and then press the corresponding button. Consequently, analyses are presented using the data from the subsequent five training sequences and, for simplicity, these are referred to as sequences 1–5.

Figure 2 summarises the mean reaction time for correct identifications of both homogeneous and heterogeneous stimuli across the five training sequences. With the data presented according to the type of image at learning (original, enhanced), it appeared that while performance generally improves across the training occasions, and while homogeneous (highly similar) stimuli are always more difficult to identify than heterogeneous (less similar) ones, performance was consistently aided by the presentation of enhanced images.

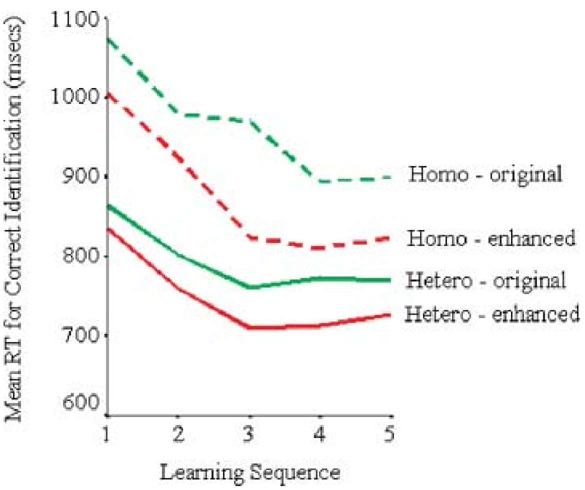

Figure 2. Mean response time for correct identifications (msecs) across training sequences for original and enhanced homogeneous (dashed lines) and heterogeneous (solid lines) aircraft

DOI: 10.1002/acp

Analysis of response latency was conducted by means of a three-way mixed Analysis of Variance (ANOVA), with stimulus similarity (homogeneous, heterogeneous), type of learning image (original, enhanced) and learning block (1–5) as independent variables. This confirmed the above observations. Stimulus similarity had a clear effect on response latency ($F(1, 111) = 109.56$, $p < .001$), with the homogeneous stimuli taking longer to correctly identify than the heterogeneous stimuli. In addition, a clear improvement across training occasions was evident ($F(4, 108) = 31.68$, $p < .001$), with improvement having a significant linear ($F(1, 108) = 103.46$, $p < .001$) and quadratic ($F(1, 108) = 17.7$, $p < .001$) component to it. The extent of improvement was somewhat contingent on the level of stimulus similarity ($F(4, 108) = 5.08$, $p < .001$). The more difficult homogeneous stimuli showed greater improvement across the training occasions ($F(4, 108) = 21.78$, $p < .001$) than the heterogeneous stimuli ($F(4, 108) = 15.22$, $p < .001$) and understandably showed less levelling off of performance across the training occasions as improvement continued.

More pertinent for the present study is the fact that the type of stimulus image shown during the training phase had a significant impact on performance ($F(1, 111) = 5.85$, $p < .025$). The presentation of enhanced images led to significantly faster response latencies than the presentation of original images, and this effect was consistent regardless of the initial similarity of the stimuli, or the stage of training. No other interactions emerged to qualify these effects.

Performance during testing

Aircraft identification performance was examined on two occasions using novel stimulus orientations, and using images that either matched or did not match with the type of image (original, enhanced) shown during the learning sequences. As such, the present design allowed the examination of the benefit of caricatured images at (i) a learning and (ii) an over-learning stage in the development of proficiency and expertise. It was expected that the more similar homogeneous stimuli would be more difficult to identify than the more distinct heterogeneous ones, as revealed through longer response latencies. In addition, the training and testing conditions themselves were expected to have an effect on performance, with the presentation of enhanced images at both training and testing predicted to represent the most desirable set of conditions. Over testing occasions, however, both effects might be expected to dissipate given the opportunity for over-learning. These predictions would be borne out by the emergence of a four-way interaction.

Figure 3 below summarises the response latency for correct identifications for both tests, and from this it appeared that performance was generally improved from first to second test but in a manner that was affected by the similarity within the stimuli, and the training and testing conditions themselves.

Analysis of the response times for correct identifications was conducted by means of a four-way mixed ANOVA, with test occasion (1, 2), stimulus similarity (homogeneous, heterogeneous), training image (original, enhanced) and test image (original, enhanced) as the independent variables. The data was consistent with the theoretical cognitive analysis. First, a main effect of stimulus similarity emerged ($F(1, 109) = 127.20$, $p < .001$), with the more similar homogeneous stimuli taking longer to correctly identify than the heterogeneous stimuli. In addition, a main effect of testing occasion emerged ($F(1, 109) = 45.56$, $p < .001$), with performance showing significant improvement from first to second testing occasion. The degree of improvement was, however, different across

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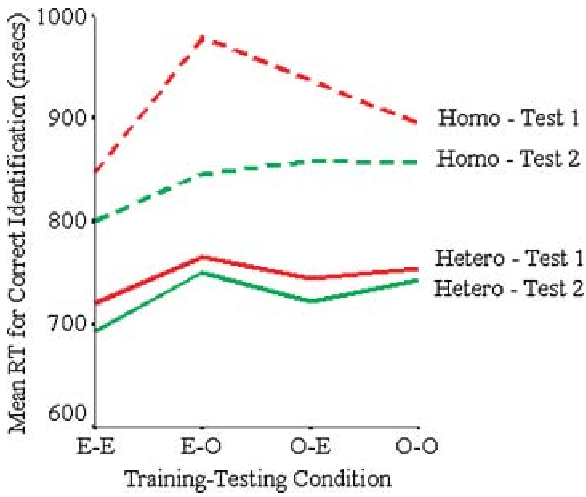

Figure 3. Mean reaction time (msecs) for correct identification of homogeneous (dashed lines) and heterogeneous (solid lines) aircraft during preliminary testing and final testing across original (O) and enhanced (E) training and testing conditions

homogeneous and heterogeneous stimuli ($F(1, 109) = 22.45$, $p < .001$) and was affected by the combination of training and testing conditions ($F(1, 109) = 5.23$, $p < .025$). However, all effects were moderated by the emergence of the expected four-way interaction ($F(1, 109) = 7.14$, $p < .01$).

Post-hoc analyses were performed to enable the interpretation of this interaction. First, two three-way ANOVAs confirmed that the interaction of level of similarity, training image and testing image only emerged on the first testing occasion ($F(1, 109) = 5.22$, $p < .025$). By the second test, performance had improved to such a degree that artificial help in the form of the combination of training and testing conditions had no effect ($F(1, 109) < 1$, $p > .05$). Examination of the initial test performance further showed that the training and testing conditions only exerted an effect on performance when the stimuli were initially difficult to identify (homogeneous) ($F(1, 109) = 4.57$, $p < .05$). When the stimuli were easy to learn and recognised readily (heterogeneous) performance was again unaided by enhancement at training or testing ($F(1, 109) < 1$, $p > .05$). Finally, taking the performance with homogeneous stimuli at the first testing occasion only, examination of the training and testing conditions revealed that reaction times for correct identifications were significantly faster following benefit or assistance *at both training and testing* (learning and being tested on enhanced aircraft images) than when a benefit was given at either learning or testing, or neither opportunity ($t(111) = 1.998$, $p < .05$).

This finding confirmed our initial predictions. Performance was significantly improved when participants had the advantage of a double benefit (image enhancement, *and* image compatibility from training to test) than when they had a single benefit only (image enhancement at training, image enhancement at testing or image compatibility across training and testing). Consequently, taken with the results from the training phase itself, the present data have confirmed the importance of stimulus characteristics to a learning and a subsequent recognition task for complex visual stimuli, and the importance of stimulus enhancement (caricaturing) before an over-learning stage is reached.

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DISCUSSION

The present results have provided a clear and consistent picture. Both when learning and when subsequently identifying previously novel non-facial stimuli, caricatured images provided a benefit. Furthermore, these results emerged despite the change of image orientation from training to testing. This suggested that the caricatures can facilitate processing and thus can be an important tool in enhancing learning. The fact that this benefit did not emerge for all exemplars is important and supported the intuition that caricatures would facilitate processing when, and only when, the task of discriminating between exemplars was sufficiently difficult to warrant the assistance. When stimuli were easily distinguished, as in the case of the heterogeneous subset of exemplars, then participants did not require assistance from caricaturing.

As important, however, the present results have addressed the issue of how caricature effects interact with, and contribute to, the development of different stages of learning. Here, the results show that benefit provided by learning from caricatures was greater towards the middle and end of the training phase, and this was especially marked for the more difficult homogeneous stimuli.

However, it is the identification data that provide the formal test of the influence of expertise on the caricature advantage. Here, the results clearly showed that caricatures at learning and test provided the best performance on a recognition task, but that this benefit is attenuated as participants acquired more and more proficiency with the stimuli. Consequently, by the second identification test, no effect of learning or testing condition emerged, even when stimuli belonged to the more difficult homogeneous subset. By this stage, it might be anticipated that participants had become so familiar with the stimuli that they could perform the recognition task adequately even from undistorted images, and that caricaturing did not provide any additional significant benefit.

In a sense, over-learning had thus created a ceiling level of performance which could not be enhanced any further. Thus, caricatures enable to shorten learning, and avoid further need for learning and over-learning. Furthermore, when learning is restricted, caricatures are an important alley in achieving relatively difficult learning in relatively short amount of time. In either case, caricature can enhance the effectiveness of learning.

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