The effects of massive repetition on speeded recognition of faces

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Models of face processing suggest that recognizing a person should prime recognition of a consecutive, but different, image of the same person. This prediction is tested in four experiments using large blocks of different views of the same person. The experiments demonstrate that reaction times decreased according to a negative power function as the number of repetitions increased. After sufficient repetitions, however, the reaction times lengthened. The presentation of a different familiar person between blocks of repetitions caused the reaction time for the target to increase to a level equivalent to that with no repetitions. Experiments 2 and 3 investigated the effect of different intervening stimuli (unfamiliar faces and objects). Such stimuli reduced the effect of mass repetition—but the reduction using a familiar face was greater than that with either unfamiliar faces or objects. Experiment 4 confirmed that the effects of massive repetition occur for a face familiarity task as well as for face identification tasks. The results are discussed in terms of the predictions of Burton’s (1994) IACL model.

There is a large body of literature that has reported investigations into the effects of repeated presentation of a face or repetition of a person’s name followed by the face (e.g., Bruce & Valentine, 1985; A.W. Ellis, Burton, Young, & Flude, 1997; A.W. Ellis, Flude, Young, & Burton, 1996; A.W. Ellis, Young, Flude, & Hay, 1987; H.D. Ellis, Ellis, & Hosie, 1993; Johnston, Barry, & Williams, 1996; Valentine, Moore, & Brédart, 1995). Throughout this literature, it has usually been demonstrated that repetition of a stimulus leads to a decrease in reaction time to identify it (i.e., priming takes place). Within the entirety of literature on face-priming experiments, however, there are very few studies that have examined the effects of more than a single repetition. The absence of studies on multiple repetitions is surprising, perhaps, for a number of reasons. First, in real-world face recognition, there tend to be multiple repetitions of the same person. Second, the models that have been proposed to account for priming effects can be extended easily to generate predictions for multiple repetitions. One could argue, therefore, that there are both

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practical and theoretical reasons for testing the nature of multiple repetition of faces on face recognition. Moreover, there are questions to be asked about possible relationships between repeated face presentation and repetition of stimulation in any biological system. Ought we, for example, to expect first a diminishing effect and then, perhaps, a habituation-induced rebound effect (or satiation) so that any progressive reduction in reaction times is reversed (see Lewis & H.D. Ellis, in press; Smith, 1984)?

Parallel experiments to those reported here investigated the effects of multiple, non-consecutive repetitions over long periods of time (Lewis & H.D. Ellis, in press). This previous study focused upon repetition priming of faces, which is a robust and well-researched phenomenon. As explained, repetition priming is the advantage observed when a face has been seen previously (e.g., Bruce & Valentine, 1985). This effect is not disrupted by intervening items and can last for many months (Flude, 1993; Maylor, 1998). Further, repetition priming can occur between parts of faces as well as whole faces (Johnston et al., 1996) and between different views of faces, but to a reduced degree (A.W. Ellis et al., 1997). The repetition priming effect, however, only occurs within a modality: A face will prime a face but not a name (although see Burton, Kelly, & Bruce, 1998). In addition to faces, repetition priming has been found with names (Johnston & Barry, 1999; Valentine et al., 1995; Valentine, Moore, Flude, Young, & Ellis, 1993), voices (H.D. Ellis, Jones, & Mosdell, 1997; Schweinberger, Herholz, & Stief, 1997), and words (Monsell, 1991; Scarborough, Cortese, & Scarborough, 1977).

Another form of priming that must be considered is associative (or semantic) priming. This is the advantage in recognizing a face when it is immediately preceded by the face of a closely associated (or semantically related) person (Bruce & Valentine, 1986). For example, seeing Prince Charles will decrease the time required to recognize Princess Diana if her face is presented immediately afterwards. This associative priming is short lived (just a few seconds) and is interrupted if another face occurs between prime and target. Associative priming is also different from repetition priming in that it is inter-modal (the target and the prime can be from different modalities). For example, the voice of Prince Charles will prime the recognition of Princess Diana as long as the two stimuli are consecutive.

The studies reported here examined the effects of consecutive repetition of different views of the same person. In this way it was hoped to focus on effects that, perhaps, are similar to those known as self priming, which, like associative priming effects, are short lived and so only occur between consecutive trials. The term self-priming is usually taken to indicate priming between modalities, but here the effect of self-priming within a modality is explored. This issue is discussed in more detail in the following section.

Self-priming

Out of the large literature that priming in face recognition has generated, there is, surprisingly, only a handful of papers that report investigations into self-priming. As the literature is so limited, it is possible to review it exhaustively. Burton, Bruce, and Johnston (1990) first used the term self-priming in face recognition to describe a prediction from their work conducted in order to implement the Bruce and Young (1986) face recognition model upon a connectionist platform. The resulting model (which is fully
described later) has greatly influenced the subsequent development of face-processing theory in general, and, specifically, it has helped to explore the implications of self-priming.

Young, Flude, Hellwell, and Ellis (1994) reported an experiment (Experiment 4) where face primes (250-ms presentation) were used to prime name targets (after an interval of 250 ms). The conditions included the prime and the target being the same person, associated people, neutral people (i.e., prime was an unfamiliar face), and unrelated people. This study found that the same-person-primed names were recognized significantly faster than those in any other condition. The results, therefore, demonstrated both the existence of self-priming and the fact that it was significantly more powerful than associative priming.

An important contribution to the investigation of self-priming was made by Calder, Young, Benson, and Perrett (1996). In this study they reproduced the effects of self-priming while at the same time investigating distinctiveness and degree of caricature. They found that the self-priming effect was larger for distinctive faces than for typical faces and for caricatures than for veridical faces. As well as a more detailed replication of the self-priming effect, this study presented a connectionist implementation that clarified the predictions of face recognition models.

A further study that investigated self-priming was conducted by Calder and Young (1996). This study compared the size of the effects of priming within and across domains (i.e., face primes and name targets or name primes and face targets). The results demonstrated that within-domain priming was greater than across-domain priming (i.e., a face primed a face more than a name primed a face). The experiments reported in the next section explore massive repetition which is a form of within-modality self-priming. Calder and Young’s study implies that the effects seen with mass repetition should be larger than those seen with traditional cross-modal self-priming.

Finally, H.D. Ellis et al. (1997) conducted several experiments that contrasted the effects of immediate repetition and delayed repetition. Their findings support the dichotomy of self-priming and repetition priming with only the immediate (self) priming acting between modalities (between voice and face recognition).

Models of face recognition and massive repetition

There exist two popular connectionist accounts of face processing: the interactive activation and competition (IAC) model proposed by Burton, Bruce, and Johnston (1990, further developed by Burton, 1994), and a model offered by Farah, O’Reilly, and Vecera (1993), which will be referred to as the FOV model. There are many similarities between these models; for example, each employs interactive activation to spread excitation between units, and they use Hebbian update to learn. In a recent review of models of face recognition (Young & Burton, 1999), Burton and colleagues’ IAC model was contrasted with the connectionist FOV model. One difference between the two models is that the IAC model employs localist representations whereas the FOV model uses distributed patterns of representation. Each model was deemed capable of accounting for a large amount of information, such as repetition priming and preserved covert recognition in prosopagnosia. Young and Burton demonstrated that one important difference between
the models, however, is that the FOV model is incapable of modelling any short-term effects caused by the immediately prior stimulus. This failing is due to the fact that, for each presentation of a stimulus, the FOV model settles into strong attractor states and, once in such a state, presentation of a further stimulus will not change this attractor state. The activation state of the model, therefore, must be reset after presentation of each stimulus, thereby removing any possible effects of the prior stimulus. In a response to Young and Burton's (1999) comments, however, O'Reilly and Farah (1999) presented a modified version of the model that could simulate the effects of immediate previous stimuli. The method employed was to present the prime and allow the model to settle into an attractor state. The activation states of units were then decayed by a factor of 90%, which took the model out of the strong attractor state but left the primed semantic units with a residual 10% activation (sufficient activation to prime or interfere with the next stimuli). Given the level of similarity of these models only the IAC model is considered in detail. This is because it is expected that the FOV model will make similar predictions, although as it is unclear as to how the FOV model can account for the effects of massive repetition of faces considered here, further modification may be required—albeit post hoc ones.

Burton (1994) described how a learning algorithm could be incorporated into the original IAC model to account for the learning of new faces. The resulting model (IAC with learning or IACL) maintained a similar overall architecture to the original and employed local representations of faces, identities, and semantic information. These three levels of representation are stored as nodes in three interconnected layers (see Figure 1). Each node has a particular level of activation that can vary over time and is affected by both the activation state of other units and the particular input representation. Nodes, or units, within a layer inhibit each other, and units between layers can excite one another if they are associated. The process of recognition starts when an input first activates a particular face recognition unit (FRU in Layer 1), which in turn activates an associated person identity node (PIN in Layer 2). Recognition is deemed to occur when the activation state of the PIN reaches a pre-defined threshold. The time taken (i.e., number of processing cycles) to reach the desired activation following a particular input is determined by many factors, including the particular parameters of the model, the strength of the input pattern, the strength of the connection between the FRU and the PIN, and the activation state of the units prior to presentation of the input. Although all these factors are important in different ways, the most significant for the present study is the final one mentioned. The PINs act as a multi-modal gateway linking different levels of information about an individual. Extraction of a piece of semantic information requires activation of the relevant semantic information unit (SIU in Layer 3) but this must be mediated by the PIN (see Figure 1).

In normal, unprimed recognition, the PIN of the associated person needs to rise from a resting level to a threshold level before recognition can take place. The time, or number of processing cycles, required to reach the threshold acts as a measure of reaction time. After that person has been seen (i.e., the stimulus input is removed) the activation of the associated PIN will decay correspondingly and eventually return to the resting level; however, this decay may take some time. In self-priming, the recognition of a person follows after encountering another representation of that person either from the same
modality (e.g., two different views of the same person) or from different modalities (e.g., a person's name and his or her face). If the interval is small enough, so that the activation level is still decaying, then there will be some residual activation, and the starting activation will be higher than the resting level. This residual activation would mean that fewer cycles (and therefore less time) would be required before the threshold is reached. In this way, self-priming leads to faster recognition—and, indeed, that is what has been found in the few studies that have investigated self-priming.

According to the IACL account of self-priming, the effect would be relatively short lived (depending on the size of the decay constant), and the priming effect should be removed by presentation of another person between the prime and the target. The intervening item would raise the activation of a different PIN, which, in turn, would inhibit the original PIN and hence reduce any residual activation. Mass repetition is effectively repeated self-priming, and so mass repetition of different views of the same person would have the same locus of effect. The explanation for any benefit seen in recognition following mass repetition, therefore, would be the same as that for self-priming.
The repetition priming effect is thought to be caused by a fundamentally different process from that which leads to self-priming and associative priming. The process considered to underlie repetition priming was described by Bruce and Young (1986) and was formalized into the computational model by Burton (1994). In order to account for repetition priming, the original model (proposed by Burton et al., 1990) had to be modified so that learning in the model could take place. This modification made use of Hebbian update to increase the strength of the connections between units (i.e., if two units are activated at the same time then the strength of connections between those units is increased by an amount proportional to the product of their activation levels). This interactive activation and competition with learning (IACL) model can account for repetition priming as follows: In the first block (the priming block) of an experiment a person is recognized; this recognition activates the FRU and the PIN associated with that person. Hebbian update leads to a strengthening of the connection between those two activated units: Subsequent recognition, regardless of any intervening items, will be faster because the connections between the FRU and the PIN are now stronger—this type of priming occurs within modality only because it occurs at the link between the FRU and the PIN rather than just at the PIN level, which is amodal (H.D. Ellis et al., 1997).

Lewis and Ellis (1999) implemented a small version of the IACL model in order to investigate its prediction for multiple, non-consecutive repetition of faces. They found that, by applying Hebbian update, the number of cycles required to reach threshold followed a negative power function. Such a pattern of results was also found in the experiments conducted on human performance of categorizing faces. A consequence of this research is that most of the effects of non-consecutive repetition take place within the first few repetitions. Subsequent repetitions have only a very small effect on the number of cycles required for the IACL model to reach threshold or on the reaction time for participants to make a face categorization judgement.

A simulation of massive repetition

The IACL model can be used to account for what would happen if the pictures of the same person (but different views of that person) are presented repeatedly at a constant rate. The residual activation of the first presentation should lead to a higher level of activation during the second presentation. When the activation decays after the second presentation the resulting residual activation will be higher than the original residual activation, and thus the twice-primed image will be recognized even more quickly than the single-primed image. Consecutive repetitions lead to further increases in the residual activation and, consequently, further decrease the reaction times towards some asymptotic level.

This speculative prediction of the IACL model can be confirmed by implementation of a simple version of the model. A two-unit IACL model was established using the parameters detailed in the Appendix. The model assumes that there is no Hebbian update (it has already been demonstrated that such a model with Hebbian update leads to a negative power function, Lewis & Ellis, 1999). It is intended to model the situation in which repetition priming has led to asymptotic responses and so additional reductions in reaction time must be due to residual activation. An input value of one was provided for 25
cycles, followed by an input of zero for 15 cycles. This pattern was repeated eight times. The number of cycles required to reach a pre-defined threshold was recorded for each set of cycles. It was observed that this number decreased as the implementation continued and that the decrease followed a negative power function ($R^2 = .963$, see Figure 2). This fit was better than either a linear or an exponential relationship.

Whether or not one observes continually decreasing reaction times for repeated repetitions, of course, must be tested empirically. The experiments described here investigate what happens when different views of the same person are repeatedly presented a large number of times. In particular, the experiments are used to examine the nature of the effect of these mass repetitions on recognition times.

The limited degree to which self-priming and, consequently, mass repetition has been investigated provokes many more questions than answers. The IACL model makes clear predictions about the effect that massive repetition should have on recognition; the following four experiments were designed to investigate whether these predictions are consistent with the empirical findings. Experiment 1 investigated the change in reaction times for up to 35 consecutive repetitions of different views of the same person. The blocks of consecutive views were separated by a single trial with a different famous person. Experiments 2 and 3 only examined up to 10 consecutive repetitions but in these

![Figure 2](image)

Figure 2. Mass repetition as modelled by the IAC model. As the number of repeated trials increases, the number of cycles required to reach threshold decreases. The line indicates the best fit power curve.
two experiments the intervening trials between blocks were varied and could be a famous face, an unfamiliar face, or an object. Experiment 2 employed a random schedule of presentation of trials, whereas Experiment 3 employed a fixed schedule (although, in fact, participants were told it was random). The fixed schedule allowed the dual effects of repetition priming and mass repetition to be investigated at the same time. Experiment 4 explored whether the effects of mass repetition still occur when the task is a face familiarity decision. As this task requires only activation of the PIN, and not the possible activation of SIUs, then this experiment determines whether at least some of the effects occur at the level of the PIN.

**EXPERIMENT 1**

The aim of this initial experiment was to investigate the effect of repeated identification of different views of one particular person. In order to conduct the experiment it was necessary to employ pictures of a person who was well known and for whom there was no shortage of different pictures available. It was decided to use images of one of the most photographed women in the world, Diana, Princess of Wales (Diana).

To make the recognition of Diana a choice task, it was necessary to include in the design another set of faces. This stimulus set did not require so many images but it was considered important that the person be similar to Diana (i.e., young, female) so that no single unique feature could be used to distinguish the two individuals. The images employed for this were of Sarah, the Duchess of York, who is often referred to as Fergie, which will be the abbreviation used here. Fergie, of course, was also semantically related to Diana.

Although the effects of massive repetition are the primary focus of all the experiments reported here, repetition priming is important because its presence may exert a confound. In order to reduce any possible repetition priming effects, the first 10 repetitions or the first block of Dianas were always removed from the analysis. Research conducted by Lewis and Ellis (1999) has shown that the size of the effect of repetition priming decreases as the number of repetitions increases: For example, the decrease in reaction times between the first and second repetitions is approximately 170 ms, whereas the decrease between the eleventh and twelfth repetitions is approximately 6 ms. By only considering repetitions beyond the tenth in the experiment, it was hoped that the effect of repetition priming would be considerably smaller than the effects of self-priming, which are the focus of these experiments.

The hypotheses for this experiment were: (1) that repeatedly recognizing a person in consecutive trials would lead to faster recognition (and, according to the IACL model, that the reaction times would follow a negative power curve); (2) that an intervening face within a run of the images of the target person will “reset” the reaction times for the next block of target faces (i.e., take the reaction times back to a level equivalent to that with no repetition).
Method

Participants

Four psychology undergraduates received course credit for their participation in this study. All participants had reported that they knew and could recognize both Diana and Fergie.

Stimuli

The stimuli consisted of 80 different digitized images of Diana and 4 digitized images of Fergie. These images were trimmed so that they only contained the heads of the person. Further images were generated by flipping the original images about the vertical axis and scaling the images (both flipped and original) by 67%. In this way, 320 images of Diana and 16 images of Fergie were available. The images were presented in greyscale on a computer monitor and subtended a visual angle that ranged between 4° and 9°. Nothing in the photographs could act as a cue to identity except the faces themselves.

Procedure

Participants were presented with a sequence of faces and were required to indicate whether each face was that of Diana or Fergie by pressing one of two keys. It was stressed to participants that both speed and accuracy were important. There was an interval of one second between each trial.

The experiment began with an introductory block of 10 Diana trials followed by 2 Fergie trials. All subsequent trials were randomized such that the length of a block of uninterrupted Diana trials was variable. The probability of any trial being a Fergie trial was uniform, regardless of how recently the last Fergie trial had appeared.

Design

The dependent variable was each participant’s reaction times for correct recognition of the images of Diana. The independent variable was the number of previous Diana trials in the current block.

Results

The reaction times for incorrect responses to images of Diana were removed from the analysis (these made up less than 1% of the data). The number of errors for the Fergie trials was much higher, with an average of 39% errors. Given such a large number of errors it is possible to investigate whether the number of previous Diana trials or the reaction time immediately prior to the error has any influence on the probability of an error being found. Unpaired t tests were conducted on the number of Diana trials and the reaction time to the Diana trial prior to the Fergie trial. These analyses found that the size of the Diana block prior to an error (mean = 22.7) was not significantly different from the size of a block prior to a correct response (mean = 18.7), \( t(78) = 0.921, p = .4 \), and, further, that the average reaction time to the Diana trial immediately prior to an error on the Fergie trial (283.0 ms) was marginally shorter than the reaction time prior to a correct Fergie response (296.2 ms), \( t(78) = 0.784, p = .4 \).
The large number of errors on the Fergie trials means that how these errors are dealt with, as regards the Diana trials, is of great importance. The most conservative method, and the one adopted here, was to disregard the entire block of Diana trials following an incorrect response to a Fergie trial. This meant that a single error would lead to the removal of a large block of data but in this way it was possible to be confident that any effects observed result from the observed presentation of the Fergie trial. Other methods of dealing with the errors were employed including removing all trials prior to an error on a Fergie item and not removing any of the trials. These analyses found the same pattern of significance in the data as the method reported. The first block of Diana trials for each participant was also removed from the analysis in order to allow a practice period and to minimize repetition priming effects.

For each participant, the mean reaction times of the responses to Diana trials were calculated for each position in the block. The trial position number was limited to 25 trials although, owing to the random order of presentation, one block ran for 64 trials. The mean reaction times of these 25 trial positions are shown in Figure 3. These means decrease steeply over the first six trials, and then there is a gradual increase in reaction times as the trial position increases.

Figure 3. The mean reaction times to recognize Diana correctly plotted against the number of times Diana had been consecutively repeated in Experiment 1. The line indicates the best fit curve from the regression. The error bars show standard errors.
The phenomenon under investigation was the effect of massive repetition on face identification, which the IACL model in the implementation described earlier predicts should follow a power function in the relationship between number of repetitions and reaction times. In order to conduct a power analysis on the data, the dependent and independent variables were natural log transformed. Owing to the fact that the data show an eventual increase in reaction times, which cannot be accounted for by a power curve, an additional factor was incorporated into the regression. The untransformed number of repetitions was used as the second factor. Although this second factor is correlated to the main factor, it is still included because without it the residuals from the simple power analysis display a marked non-linearity. The presence of this second factor removes this non-linearity but care must be taken when interpreting these factors. The resulting regression had two independent factors. The global fit of the analysis was significant, $R^2 = .789, F(2, 22) = 41.1, p < .0001$. Both the log-transformed number of repetitions, $r = -.557, t(22) = 8.686, p < .0001$, and the untransformed number of repetitions, $r = -.254, t(22) = 7.056, p < .0001$, significantly predicted the reaction times (however, the log-transformed factor was significant both on its own and in the presence of the second factor, whereas the untransformed factor was only significant in the presence of the transformed factor). The curve of best fit, as predicted by this regression, is shown in Figure 3.

Discussion

There are two important features of the results, which are evident from the non-monotonic nature of the reaction times. Over successive repetitions, the reaction times initially decrease and subsequently increase—this suggests, perhaps, two separate processes, which are discussed independently.

By far the stronger of the two processes was the decrease in reaction times seen over the first six consecutive repetitions. This result demonstrates that identifying a person repeatedly and consecutively acts progressively to lower the reaction time for subsequent identification and that this effect fits a negative power function. The consequence of this result is that the improvement in reaction times can be facilitated by immediate repetition beyond the first repetition—but the degree of improvement decreases over subsequent trials. This result can be interpreted as mass repetition leading to priming of recognition, and the size of the priming effect is related to the number of repetitions. Also, it was found that the presence of a single trial of a different familiar person was sufficient to reset the reaction times to those for a trial with no repetition (the first Diana trials were not significantly different in reaction times from the Fergie trials).

The second feature of the results is a gradual increase in the reaction times following six or more repetitions. This effect was found to be significant when modelled by an additive near-linear factor in the regression analysis. Initially, the effect of this factor is much smaller than that of the priming-power curve but after six repetitions it exerts a

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1 By employing the log of the number of consecutive repetitions a value of zero could be attributed to the unprimed occurrences. This was considered to be more useful than taking the log of the number of previous occurrences that would lead to the unprimed occurrence being omitted from the regression.
larger influence on the reaction times than the priming-power curve. This result was surprising and is not predicted by the IACL model (nor the FOV model). One possible account for this effect is that the participants are becoming habituated to the stimulus (as demonstrated by Lewis & Ellis, in press). However, an alternative account that cannot be avoided is that after a long block without a Fergie trial, participants were preparing for such a trial (i.e., a criterion shift). Therefore, the effect observed is a change in the response bias. This result reflects a change in attentional factors in much the same way as Robertson, Manly, Andrade, Baddeley, and Yiend (1997) found on a sustained-attention-to-response task. Robertson and colleagues found that erroneous key presses to a rare distractor item were more common immediately following trials with faster times. Tentative support for this shift in response bias comes from the analysis of the trials immediately prior to the Fergie errors: Faster trials were followed by more errors but this effect was not significant. The data from Experiment 1 are inconclusive as to why an increase in reaction times occurs for large numbers of repetitions. Further investigation of this phenomenon is required to understand fully the effects of massive repetition; however, this is not reported here as there are many other questions concerning massive repetition that require attention.

EXPERIMENT 2

An important finding from Experiment 1 was that an intervening familiar face between a series of blocks of Diana trials resulted in a resetting (or near resetting) of reaction times for identification of those items. It was hypothesized earlier, using the IACL model, that the increase was caused by the presentation of a familiar face, resulting in a decrease in the residual activation of the Diana PIN—that is, the activation of the Fergie PIN during the intervening trial inhibits the Diana PIN and reduces its residual activation.

According to this hypothesis, the intervening item must be associated with an existing PIN for the step in reaction times to occur following that item (only activated PINs inhibit other PINs). Burton et al. (1990) suggest that unfamiliar faces do not have associated PINs, and thus presentation of such an image should not lead to a reduction in the Diana PIN’s residual activation, and therefore there should be no sharp increase in reaction times to identify Diana following such an item. Experiment 2 aimed to test this hypothesis by examining identification of a series of blocks of Diana trials separated either by Fergie’s face or by an unfamiliar face.

Owing to the nature of any task involving faces, there are parts of the response times that are due to face recognition system and parts that are due to more general aspects of cognition (Bruce & Young, 1986). In the current example, the response times are affected by the activation state of the Diana PIN but also they may be affected by the activation state of other parts of the route from stimulus to response. To investigate how much of any difference is due to aspects of massive face repetition and how much specifically results from response priming, two conditions were included in which the intervening items were photographs of either unfamiliar faces or objects. Any increase in activation following these intervening items can be attributed either to the time delay between the non-consecutive Diana trials or to response priming (that is, the advantage for making the same response again beyond any face-priming effects).
A further difference between Experiment 2 and Experiment 1 is that the former employed only the original 80 views of Diana. This change was made because it has been found, with objects at least, that reversal and scaling does not stop repetition priming between images from occurring (Biederman & Cooper, 1991). This fact does not change the implications of Experiment 1, as the size of repetition priming over the whole experiment would be much less than the observed effects of massive repetition; however, in Experiment 2 only the original 80 Diana views were employed.

The hypothesis of Experiment 2 was that the resetting of the effects of mass repetition would be larger when a familiar face was used as a distractor than when an unfamiliar face or an object was used.

**Method**

**Participants**

Twelve undergraduates received course credit for their participation in this study. All participants had reported that they knew and could recognize Diana and Fergie, and none of the participants had participated in Experiment 1.

**Stimuli**

The stimuli consisted of the 80 digitized images of Diana and 4 digitized images of Fergie, as used in Experiment 1, plus 6 additional images of Fergie. Unlike in Experiment 1, only original images were used (the flipped and scaled images were not used for Experiment 2). In addition to these familiar faces, a set of 10 unfamiliar faces (young female faces) and 10 household objects (e.g., a kettle, a hammer, etc.) was used. The Fergie faces, the unfamiliar faces, and the objects are collectively referred to as distractors owing to their relation to the Diana faces in the Diana categorization task. The images were presented in greyscale on a computer monitor.

**Procedure**

Participants were presented with a sequence of images, and their task was to indicate whether or not each image was Diana by pressing one of two keys. The three categories of image that could be classified as “not Diana” were explained to all participants as being pictures of Fergie, pictures of people they probably had not seen before, or pictures of objects. After participants had made their responses to each image there was a 1-s interval before the next image appeared. The experiment was split into three sections in which each of the sets of distractors was employed. The participants were informed which images would make up the distractors before commencing each section. The order of the three sections was counterbalanced between participants.

The presentation of the images within each section was randomized so that any trial had the same probability of being a Diana trial. Each section consisted of 80 Diana trials and 10 distractor trials.

**Design**

The dependent variable was the participants’ reaction times for correct recognition of the images of Diana. The independent variables were the number of previous consecutive Diana trials and the nature of the intervening distractor images within the section (i.e., Fergie, unfamiliar face, or object).
Results

Errors made up less than 1% of the responses to Diana trials, and these were removed before the data were analysed. There were considerably more errors in the distractor trials (33% errors—there was no significant difference between the conditions). The same method of dealing with these errors was employed as that in Experiment 1; that is, all Diana trials in a consecutive block immediately following an error were removed from the analysis. The first block of Diana trials was also removed from the analysis. The remaining reaction times for Diana trials up to the first 10 consecutive trials in each block were analysed.

The means over the 12 participants are shown in Figure 4, which illustrates how the reaction times decrease over each of the three conditions as the number of consecutive repetitions increases. A power regression was performed on the data averaged across participants. This power regression was performed using the log of the reaction times to categorize Diana as predicted by the log transform of the number of previous consecutive Diana trials. The blocks in Experiment 2 were shorter than those in Experiment 1, and so it was not necessary to consider the linear increase seen over very large numbers of repetitions. Two dummy variables were used to represent the intervening items in the

![Figure 4](image-url)

**Figure 4.** The mean reaction times to recognize Diana correctly plotted against the number of times Diana had been consecutively repeated and the type of distractor in Experiment 2. The lines indicate the best fit curves for each condition, and the error bars show standard errors.
regression. The first of these dummy variables was +1 whenever the intervening item was a face and −1 when the intervening items were objects (this variable was labelled “distractor facedness”). The second dummy variable was +1 whenever the intervening item was Fergie and −1 when the intervening items were either unfamiliar faces or objects (this variable was labelled “distractor familiarity”). All the interactions between the number of consecutive repetitions and the distractor variables were included in the regression model, making a total of five factors.

The global fit of the power regression was significant, $R^2 = .961$, $F(5, 24) = 118.7$, $p < .0001$. The analysis found a significant negative effect of consecutive repetitions, $r = −.799$, $t(24) = 6.499$, $p < .0001$, which replicates that found in Experiment 1. There was also a significant effect of distractor familiarity, $r = .978$, $t(24) = 23.240$, $p < .0001$, and a further significant effect of distractor facedness, $r = .906$, $t(24) = 10.502$, $p < .0001$. These main effects were modified by one significant interaction between distractor familiarity and consecutive repetitions, $r = −.523$, $t(24) = 3.007$, $p < .01$. This interaction modifies the effect of consecutive repetitions such that using Fergie as the intervening items significantly increases the size of the effect of consecutive repetitions. This can be illustrated by conducting a regression for each of the conditions with just number of consecutive repetitions as the independent variable. In such analyses the effect of consecutive repetitions was significant in all three conditions but was largest for Fergie distractors, $r = −.858$, $t(8) = 4.719$, $p < .005$. The effect was smaller, but still significant for unfamiliar faces, $r = −.810$, $t(8) = 3.909$, $p < .005$, and smallest for objects, $r = −.647$, $t(8) = 2.403$, $p < .05$.

Discussion

The three simple regressions demonstrated that, as in Experiment 1, there was a significant negative power relationship between the number of trials since the last non-Diana item and the time required to identify Diana. This effect was significant across all three distractor conditions and in each condition individually. The fact that this effect was significant throughout the experiment, even for the object–distractor condition, means that the object trials decreased the amount of priming that is carried through to the following Diana trial. It was predicted that the decrease in priming was a consequence of interference resulting from the intervening item inhibiting the Diana-PIN and hence would not occur for objects or unfamiliar faces. The finding of a significant decreasing pattern following an object distractor implies that not all of what is seen as mass repetition effect comes from the face recognition system. A certain amount of the priming comes from the fact that the same response is repeatedly being made (i.e., response priming).

The results also show that the steepness of the power–function effect of repetition is significantly affected by the preceding distractor such that it is steeper following a Fergie distractor than following either an object or an unfamiliar face. Inspection shows that the reason for this is that it appears that the Fergie distractors interfere with Diana trials more than the other types of trial. Therefore, it can be speculated that the Fergie trial, by nature of it being a competing identity, causes a greater degree of inhibition, reducing the residual activation of the Diana PIN. The other types of distractor do not activate a PIN, and so inhibition between PINs does not occur. The difference, seen between the
priming in the object distractor condition and the priming in the Fergie distractor condition, indicates the degree of priming that is specifically due to the face-processing system.

EXPERIMENT 3

Experiments 1 and 2 did not attempt to deal with any possible interaction between repetition priming (which lasts across many trials) and mass repetition (which acts only upon consecutive trials). These experiments dealt with repetition priming by removing the first block of Diana trials from the analysis and thereby eliminating the largest effects of this factor. Experiment 3 attempts to examine simultaneously the different effects of repetition priming and massive repetition. In order to do this, it was necessary to control the number of trials in each block of Dianas. Eight blocks of 10 trials were used, and each of these blocks was separated from the next by one distractor. The participants were informed that the trials would be randomized, and to reinforce this impression the experiment began with a block of different sorts of distractor. Participants were asked after the experiment if they observed any pattern in the order of presentation. None of the participants reported noticing any such pattern.

In Experiment 2 it was found that the different distractors had varying effects on the Diana trials both in overall reaction times and in the size of the mass repetition effects. It is possible that the larger effects seen with Fergie distractors are a result of slower reaction times overall. In order to investigate this possibility, the participants in Experiment 3 were not informed which distractor items would be occurring between the Diana trials. Also, the experiment was conducted with distractor type as a between-participant variable.

Experiment 3 investigated the same hypothesis as that of Experiment 2—that is, that the nature of the intervening items affects the size of the resetting between blocks. This experiment also examined the relationship between total number of repetitions and number of consecutive repetitions prior to recognition. In this way, it was hoped to distinguish between effects of repetition priming and those of mass repetition.

Method

Participants

Thirty-six psychology undergraduates received course credit for their participation in this study. All participants had reported that they knew and could recognize Diana and Fergie, and none of the participants had participated in Experiments 1 and 2.

Stimuli

The stimuli consisted of the 80 digitized images of Diana and 10 digitized images of each of the types of distractor as used in Experiment 2 (Fergies, unfamiliar faces, and objects). The images were presented in greyscale on a computer monitor.
Procedure

Participants were presented with a sequence of images, and their task, as in Experiment 2, was to indicate whether or not the image was Diana by pressing one of two keys. The three categories of image that could be classified as “not Diana” were explained to all participants. To help motivate participants it was explained that there was a small cash prize to be awarded to the person who made the least errors and that if two people made the same number of errors then the person who had the fastest reaction times would receive the prize. After participants had made their response to each image there was a 1-s interval before the next image appeared.

All participants started by being presented with three of each of the three types of distractor image. The first of eight blocks of 10 Diana trials followed immediately after the 9 distractor trials. Each block was separated by one distractor image. The order of the particular views of Diana was randomized for each participant. The type of distractor image separating the blocks was determined by the condition the participant was in, and all intervening distractors were of the same type for each participant. Participants were not aware of which condition they were in nor that all the intervening items would be of the same type.

Design

The dependent variable was the participants’ reaction times for correct recognition of the images of Diana. The independent variables were: the number block in which the image occurred (block number, 1 to 8); how far into the block the image appeared (number of consecutive repetitions, 1 to 10), and the nature of the intervening distractor images between blocks (Fergie, unfamiliar face, or object).

Results

Errors on the Diana trials made up less than 1% of the responses, and, as in the previous experiments, these were removed before the data were analysed. The number of errors on the distractor trials was less than 10%. This value was considerably lower than that in Experiments 1 and 2—a difference that may reflect the additional incentive of the cash prize or possibly the fact that the participants did not know what type of distractor would appear in this experiment. The means of the reaction times in the three conditions are shown according to number of consecutive repetitions in Figure 5 and according to block number in Figure 6. Figure 5 shows that, in all three conditions, the reaction times fall over successive consecutive repetition of the Diana trials, although this drop is greatest in the Fergie distractor condition. Figure 6 shows that the reaction times decrease as the block number increases, although this trend is small in the Fergie distractor condition.

As in Experiments 1 and 2, a power regression was performed using the log of the reaction times to categorize Diana correctly as predicted by the log of the number of consecutive repetitions. A second predictor of block number was included to investigate any changes over the length of the experiment. The block number was log transformed before analysis, and both block number and consecutive repetitions were standardized. As in Experiment 2, two dummy variables (distractor facedness and distractor familiarity) were used to represent the intervening items in the regression. All feasible interactions between the four main variables were included in the regression model, making a total of 11 factors.
The global fit of the regression was significant using both the mean cell scores, $R^2 = .541$, $F(11, 228) = 29.2, p < .0001$, and the raw scores, $R^2 = .056$, $F(11, 2862) = 15.1, p < .0001$. The analysis found a significant negative effect of consecutive repetitions, $r = -.136$, $t(2862) = 6.026$, $p < .0001$, and a significant negative effect of block number, $r = -.061$, $t(2862) = 2.861$, $p < .01$. There was also a significant effect of distractor familiarity, $r = -.167$, $t(2862) = 4.861$, $p < .0001$. The dummy variable of distractor facedness was not significant, $r = -.006$, $t(2862) = .771$. These main effects are modified by one significant interaction that occurred between distractor familiarity and block number, $r = .046$, $t(2862) = 2.602$, $p < .001$. This interaction modified the effect of block number such that using Fergie as the intervening items significantly reduced the size of the effect of block number and, moreover, made the effect of block number non-significant within that condition. This can be illustrated by conducting a regression for each of the conditions with just block number and number of consecutive repetitions as the independent variables. In such analyses, the effect of block number was significant only when the intervening items were unfamiliar faces or objects (see Table 1). Planned pairwise comparisons were conducted to contrast the three conditions with particular reference to the condition and block number interaction. This interaction was significant when the Fergie
and object conditions were compared, \( t(1972) = 1.970, p < .05 \), and when the Fergie and unfamiliar face conditions were compared, \( t(1972) = 2.787, p < .05 \). The effect of the interaction when the object condition was compared with the unfamiliar face condition was non-significant, \( t(1972) = .588, p > .05 \).
Discussion

As in the Experiments 1 and 2, there was a significant effect of number of consecutive repetitions fitting a negative power relationship between the number of trials since the last non-Diana item on the time required to identify Diana. This effect was significant across all three distractor conditions and in each condition individually. This result confirms the conclusions made after Experiment 2 that some of the mass-repetition effect comes from outside the face-processing system (i.e., response priming).

The analysis found that there was a significant overall effect of block number; however, this was modified by the interaction between distractor familiarity and block number. Analysis of the three simpler regressions demonstrates that the effect of block number was significant only for the unfamiliar-faces-distractor condition and the objects-distractor condition. Further, the pairwise comparisons demonstrated that the condition where Fergie was used as the distractor items led to a significantly smaller effect of block number than did the other two conditions.

To interpret the effect of the interaction between distractor familiarity and block number it is necessary first to consider the simple effect of block number. The effect may be due to Hebbian update (i.e., repetition priming) during the course of the experiment—that is, during the recognition of Diana there is strengthening of the links between the FRUs and the PINs associated with the faces (i.e., repetition priming occurs). Second, the effect may be caused by some saving in the residual activation after the intervening item—that is, after the distractor item, the activation of the Diana PIN drops but it does not fall to the level it was at originally, and so some priming remains. Either of these accounts or a combination of them both can explain the effect of block number.

The interaction between the block number and the distractor familiarity goes some way to distinguishing between these two mechanisms. If Hebbian update was the cause of the block number effect then this should be unaffected by the type of intervening item—the strengthening of the links will occur no matter what additional images are presented. Alternatively, the activation-saving account would predict that the nature of the intervening item should influence the amount of saving that takes place and, therefore, ought to affect the advantage for increased block number. The interaction implies that at least some of the effect seen is due to the activation saving although it is not possible to disregard completely the possibility of Hebbian update taking place as well—but, if it does, the effect is considerably smaller than the effect of activation saving when the distractors are either unfamiliar faces or objects.

EXPERIMENT 4

Experiments 1 to 3 all involved the use of similar face identification tasks. It was argued earlier that such tasks can take place by activation of the relevant PIN; however, PINs are usually associated with familiarity-decision tasks. If it is to be argued that at least part of the massive priming effect is coming from residual activation of the PIN, then it is necessary to demonstrate its presence in a familiarity decision task. Experiment 4 employs such a task to investigate massive repetition, and, as a consequence of the design of the
experiment, it is also possible to distinguish between effects due to repetition of response and repetition of the same person.

The experimental design, in some respects, is similar to that employed in Experiment 2, although the object condition was dropped, and participants were not told what kind of distractors they would see—indeed it was indicated to the participants that the distractors would be completely random. There were two parts to the experiment that were counterbalanced between participants. In one part, the 80 Diana faces were intermixed with 8 unfamiliar faces, and in the other part the 80 Diana faces were intermixed with 8 Fergie faces. Although all the responses in the latter condition were positive, participants were not aware of this fact and still had to maintain their attention to the task. Both parts began with a number of Fergie and unfamiliar faces as a warm up and so that there were at least some negative trials in the Diana-and-Fergie condition.

The hypothesis was that both conditions would show effects of massive repetition as observed in Experiments 1 to 3. Further, the observed effects would be larger in the Diana-and-unfamiliar condition as there would be response priming in addition to priming of the PIN.

Method

Participants

Ten psychology undergraduates received course credit for their participation in this study. None of the participants had participated in Experiments 1, 2, or 3.

Stimuli

The stimuli consisted of the 80 digitized images of Diana and 10 digitized images each from two types of distractor as used in Experiment 2 (i.e., Fergies and unfamiliar faces). The images were presented in greyscale on a computer monitor.

Procedure

Participants were presented with a sequence of images, and their task was to indicate whether or not the image was a familiar person by pressing one of two keys. To help motivate participants, as in Experiment 3, it was explained that there was a small cash prize to be awarded to the person who made the least errors. After participants had made their response to each image there was a 1-s interval before the next image appeared.

The experiment was in two parts (a Diana-and-Fergie condition and a Diana-and-unfamiliar-face condition). Each part began with two of each of the two types of distractor image. Following this warm-up, the participant was presented with a random series of 80 Diana faces and 8 distractors. The distractors were constant throughout each part of the experiment. The order in which the two parts were carried out were counterbalanced between participants, and participants were not told that there would be any structure to the presentation of the stimuli.
Design

The dependent variable was the participants’ reaction times for correct recognition of the images of Diana. The independent variables were number of consecutive repetitions of Diana previous to the current one and the nature of the intervening distractor images (Fergie or unfamiliar face).

Results

Errors on the Diana trials made up less than 1% of the responses, and, as in the previous experiments, these were removed before the data were analysed. The number of errors on the distractor trials was less than 5%. The mean reaction times for each part are plotted according to the number of previous Diana trials in Figure 7. This figure shows how each condition shows a decrease in reaction times as the number of repetitions increases.

As in Experiments 1 to 3, a power regression was conducted on the reaction times to Diana faces predicted by the number of consecutive repetitions. The effect of type of distractor was incorporated into the regression as a dummy variable with value $-1$ for Fergie face distractors and value $+1$ for unfamiliar face distractors. The variables were log

Figure 7. The mean reaction times for correct familiarity judgement on the Diana trials plotted against the number of times Diana had been consecutively repeated and the type of distractor in Experiment 4. The lines indicate the best fit curves for each condition, and the error bars show standard errors.
transformed (except for the dummy variable) and standardized. The interaction between distractor type and number of repetitions was also included.

The global fit of the power regression was significant, $R^2 = .623$, $F(3, 16) = 8.830$, $p < .01$. As in Experiments 1 to 3 there was a significant negative effect of the number of consecutive repetitions (log transformed), $r = -.769$, $t(16) = 5.013$, $p < .0001$. The effect of the distractor type was not significant, $r = -.168$, $t(16) = 1.098$, $p > .05$, nor was the interaction, $r = -.059$, $t(16) = 0.387$, $p > .05$. In order to confirm that the effect of repetitions was significant for both distractor types, two simple regressions were conducted. The effect of number of repetitions was found to be significant both when the distractors were Fergie faces, $r = -.729$, $t(8) = 3.013$, $p < .05$, and when they were unfamiliar faces, $r = -.830$, $t(8) = 4.214$, $p < .01$.

Discussion

The results demonstrate that the effect of massive repetition shown earlier also occurs within a face-familiarity-decision task, and, further, this occurs regardless of whether the intervening items are unfamiliar faces or other familiar faces. This second point is important because it demonstrates that the result is not caused by response priming but, instead, it is a feature of repeated recognition.

The fact that the effects of massive repetition are observed for a face familiarity task confirms the hypothesis and indicates that the locus for at least part of the effect is at the level of the PINs. This conclusion can be made because a decision as to the familiarity of a face is considered to occur at the level of the PIN and does not require activation of SIUs.

In some ways the result with the Diana-and-Fergie condition is remarkable because, in this condition, participants kept making the same response for all the faces (both Diana and Fergie required a “familiar” response). It therefore would have been possible for participants to have ignored the face and just responded when any image appeared. Participants, however, did not know that there would be no unfamiliar faces after the initial trials, and the fact that a significant pattern is found in the analysis of response times indicates that participants were, in fact, recognizing each face.

GENERAL DISCUSSION

Experiments 1 to 4 make an important contribution to our understanding of mass repetition of faces. The results from the experiments presented here demonstrate that not only does one view of a face prime a consecutive different view of that face, but also that the priming continues to increase well beyond the first repetition. This is demonstrated by the negative power functions found in all four experiments. A negative power curve begins with a steep drop but levels to near asymptote after more repetitions. The consequence of this curve is that the first couple of repetitions will have a much greater effect on reaction times than will later repetitions. Experiment 1 found that, after about six consecutive repetitions, the reaction times began to increase again. This effect was smaller than the priming effect found and so only became apparent after larger numbers of repetitions. It was considered that this increase may be either a result of a shift in response bias or a consequence of habituation.
All four experiments demonstrated that the number of consecutive repetitions occurring since a trial with another familiar person’s face is a good predictor of reaction time for identification. Experiments 2, 3, and 4 also offer useful information on what happens when the face of a different person is inserted between trials on the repeated face compared with when either an unfamiliar face or an object is inserted. Experiment 2 found the object and unfamiliar face each caused an increase in reaction times but this increase was not as great as that with a different familiar face. It can be concluded from these results that part of the decrease in reaction times for consecutive repetitions was produced by processes that fall outside face recognition processes but that another part of it could only be explained as being specific to recognition of familiar faces.

Experiment 3 allowed the possibility of a cumulative repetition priming effect to be considered along with the effects of massive repetition. It was found that this repetition priming, or block order effect, was significant but only for conditions where the distractor was either an object or an unfamiliar face. If this result really is a cumulative repetition priming effect then it should not be affected by the nature of intervening items. The same would be true if this were a simple task practice effect. The explanation offered for the difference in this effect between familiar-face distractors and unfamiliar-face distractors is that not all of the residual activation (which gives rise to the massive repetition effect) is removed by the unfamiliar face, and so subsequent blocks start with a slightly higher residual activation than that of blocks following a familiar-face distractor. This result is consistent with the findings in Experiment 2 that demonstrated that the unfamiliar-face distractors lead to less interference than do the familiar-face distractors.

Experiment 4 demonstrated that the effects observed were not dependent on the task being a face identification task. Similar effects of massive repetition were found when the task involved a judgement of familiarity of the face. This task allowed the effects of response repetition and face repetition to be disassociated, and so it demonstrated clearly that the effects observed were not a result of participants making the same response repeatedly.

There are a number of differences between the four experiments that are worth noting. First, it can be observed that the reaction times in Experiment 4 are considerably longer than those in Experiments 1 to 3. This implies that it takes longer for people to say that a face is familiar than to say that a face belongs to a particular person. One possible reason for this difference is that in the latter case the decision is based upon the activation of just one specific PIN whereas in the former case activation of any PIN will lead to a positive response. It is possible, therefore, that monitoring a single PIN is easier and faster than monitoring all the PINs. This account is speculative and based upon a theoretical decision-making system. There are other accounts of this difference between the experiments that cannot be discounted.

A second difference between the results of the experiments is that the reaction times appear to increase after five repetitions in Experiment 1 whereas no such increase is evident in the other three experiments. Earlier, it was speculated whether the observed increase in reaction times was a consequence of attentional factors. Experiment 1 was unique both in the high ratio of Dianas to distractors and the length of the experiment. Either of these two factors may have influenced the increases in reaction times observed and may explain why they were not apparent in Experiments 2 to 4.
Implications for the IACL models

The original prediction that massive repetition would speed up face recognition was generated from an implementation of the IACL model (Burton et al., 1990). This prediction has been tested within the face domain, and the prediction has been found to be supported. The prediction of the IACL model, that this decrease in reaction times follows a negative power function, was also supported.

The experiments reported here have gone beyond the simplest predictions of the IACL model and provoke a more detailed investigation of the effects involved in mass repetition. The results suggest that the presence of just one familiar face acting as an intervening trial is sufficient to remove the effect of a series of massively repeated trials. An unfamiliar face or an object, however, reduces the effect of mass repetition but some of this effect is preserved over such a trial. It is not clear, from current descriptions of the IACL model, how unfamiliar faces or objects would be dealt with, and, hence, it is not possible to model the effects seen with these distractors. The experiments here, however, give a clear indication of what properties any model must have if it is to account for repetition effects in face recognition.

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**APPENDIX**

The implementations of the IACL model examined the activation patterns of just two linked units representing a FRU input (unit i) and a PIN output (unit j). This is based on the Rumelhart and McClelland (1988) IAC software. The equations governing the system are detailed elsewhere (e.g., Lewis & Ellis, 1999).

The global parameters were set to: \( \text{max} = 1; \text{rest} = -0.1; \text{decay} = 0.01; \text{e} = 0.1 \), and \( \alpha = 0.01 \). The initial state of the network was such that \( a_j = 0 \) and \( w_{ji} = 0.01 \). Presentation of Diana’s face was modelled by setting \( \text{extinput}_i = 1 \), and recognition was deemed to have occurred when \( a_j > 0.5 \).

The implementation consisted of 25 cycles with Diana followed by 15 cycles without Diana. This procedure was repeated eight times, and the number of cycles required to reach threshold each time was recorded.