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A matching advantage for dynamic human faces

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Abstract. In a series of three experiments, we used a sequential matching task to explore the impact of non-rigid facial motion on the perception of human faces. Dynamic prime images, in the form of short video sequences, facilitated matching responses relative to a single static prime image. This advantage was observed whenever the prime and target showed the same face but an identity match was required across expression (experiment 1) or view (experiment 2). No facilitation was observed for identical dynamic prime sequences when the matching dimension was shifted from identity to expression (experiment 3). We suggest that the observed dynamic advantage, the first reported for non-degraded facial images, arises because the matching task places more emphasis on visual working memory than typical face recognition tasks. More specifically, we believe that representational mechanisms optimised for the processing of motion and/or change-over-time are established and maintained in working memory and that such 'dynamic representations' (Freyd, 1987 *Psychological Review* **94** 427 – 438) capitalise on the increased information content of the dynamic primes to enhance performance.

1 Introduction

In his book *States of Mind*, Jonathan Miller asked Sir Ernst Gombrich, the renowned art historian, why faces are so hard to represent pictorially. Gombrich replied: "I think it is movement which is the great problem. And in particular the facial movement of expression which impresses us through its changes, through its melody ... the characteristic of the person will always be the way they move, the melody of the expression; this can never be caught in snapshots ..." (J Miller 1983). As if inspired by Gombrich's words (see also Gombrich 1960, 1982), there has recently been a growing interest in the role that motion might play in the *mental* representation of facial identity.

For example, several studies have now shown convincingly that *rigid* rotations of the head can give rise to better recognition performance when compared to static images. This appears to be true regardless of whether the motion is present at time of study (Pike et al 1997) or time of test (Schiff et al 1986). Pike et al (1997) suggest the success of this approach may be due to the fact that seeing a face continuously rotate through a variety of viewpoints facilitates the extraction of 3-D structural information. Previous studies (eg Bruce and Langton 1994; Kemp et al 1996) have demonstrated that such 3-D information may well enhance recognition performance.

Studies of the influence of *non-rigid* motion provide a picture that is far less clear. For instance, an early study by Bruce and Valentine (1988) found very little support for the notion that studying dynamic faces was any different from studying static images. However, more recently, Knight and Johnston (1997) were able to show recognition advantages for moving *famous* faces, but only when the image quality was severely reduced by presenting photographic negatives. Lander et al (1999) were able to replicate and extend this work, finding strong advantages for recognising famous moving faces using two types of degraded images: photographic negatives, as in Knight and Johnston (1997), and 'threshold' manipulated images (one-bit per pixel black and white images).

Christie and Bruce (1998), on the other hand, were unable to find recognition advantages for moving faces when participants studied *unfamiliar* faces. They suggest that this difference between familiar and unfamiliar faces could have arisen if motion were more important for *accessing* existing representations of faces, rather than for *establishing* new representations. As we become more familiar with a face, we might begin to incorporate characteristic motion as a specific cue to memory (eg Clint Eastwood's squint may be a strong cue to his identity). Lander and Bruce (2000), however, also note that there might be some 'generalised benefit' for recognising moving faces in addition to specific patterns of characteristic motion. That is, a naturally moving face may afford some immediate representational advantage compared to a static image of a face. It is unclear why such a generalised advantage should be found with famous, but not with unfamiliar faces.

The studies discussed thus far have typically explored the role of motion within the context of old/new recognition tasks. That is, performance was assessed by asking observers to judge whether they had seen a target face prior to a testing session. Memory for the old target faces could have been established before the experiment, in the case of famous faces (eg Lander et al 1999); or during an explicit study phase, in the case of unfamiliar faces (eg Christie and Bruce 1998). The existence of retention intervals between study and test, lasting at least several minutes, means that such tasks are necessarily probing long-term representations of faces.

In contrast to these old/new tasks, the studies reported here used the immediate matching paradigm shown in figure 1. On each trial, observers were shown two faces in quick succession and were asked to make a speeded response based on the information presented during that trial. In experiments 1 and 2, observers were asked to judge whether the two faces had the same identity. In experiment 3, the matched dimension was facial expression. The influence of facial motion was explored by manipulating the nature of the initial or 'prime' image. In one half of the trials this prime image was a single still image (figure 1a), and in the other it was a short video sequence (figure 1b) showing a non-rigid change of expression. The second or 'target' image was always a single still image.

Similar matching tasks have been used to study many aspects of object (eg Kourtzi and Shiffrar 1997; Sekuler and Palmer 1992) and face perception (eg Haxby et al 1995; see Haxby et al 2000 for a review). Importantly, performance in such matching tasks is thought to be mediated by information established and maintained in temporary or working memory (eg Baddeley 1986; Courtney et al 1996; Goldman-Rakic 1999; Grady et al 1998; E K Miller et al 1996). Our interest in non-rigid motion in this paradigm then is not whether it can help you to remember a previously seen face, with reference to long-term memory, but in whether it affects your ability to match recently seen, and presumably currently active, versions of a prime and target face.[(1)]

Our prediction was that the dynamic primes would lead to better performance than the static primes. Why should we expect such a dynamic-prime advantage?

[(1)] While matching tasks have proven to be a very useful tool for exploring relatively temporary, and sometimes completely novel, representations of objects, the use of such a task cannot, in and of itself, exclude the influence of long-term representations. As described in more detail below, the current experiments used a small set of faces that were repeatedly shown to observers. It is thus very likely that observers quickly established strong and stable representations of these faces. However, while such long-term-memory representations of the faces would almost certainly be accessed during each trial, there is little reason to believe they would have a direct impact on matching performance. Observers had equal exposure to all of the faces (ie there were no old/new distinctions or any other differences in familiarity) and each face was seen moving as often as it was seen statically. The long-term representations of each face were, therefore, never directly probed or manipulated as part of the matching task. What was manipulated was the relationship between the prime and the test image within a given trial. That is, on some trials the prime face was moving and on others it was not. The focus of matching responses was thus the currently active representation of the prime and target faces, which we claim would be maintained in working memory.

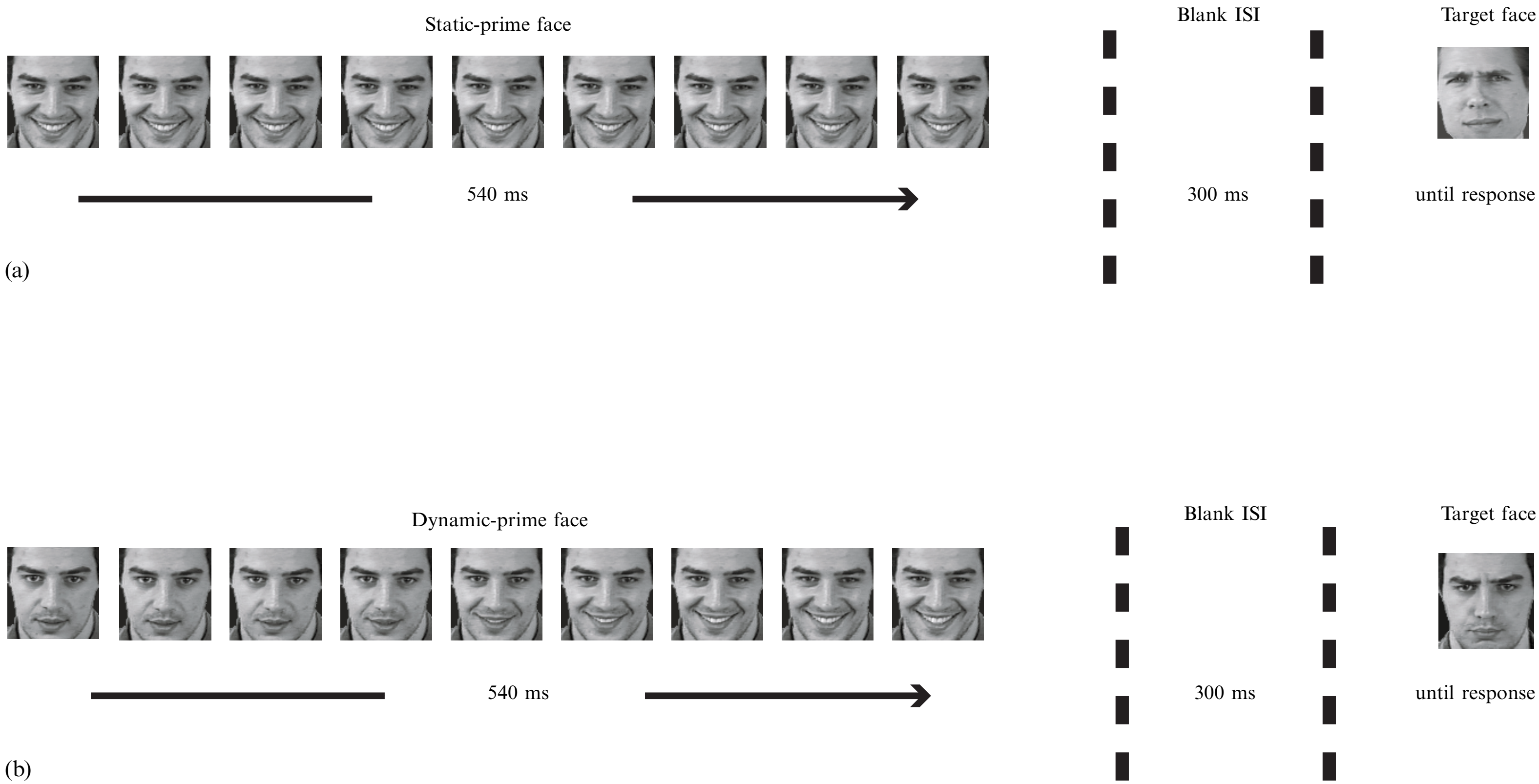

Figure 1. The face-matching paradigm used in experiments 1 – 3. For static-prime trials (a), a single still image was continuously shown for 540 ms. For dynamic-prime trials (b), an 18-frame video sequence was displayed. Each frame of this sequence had a duration of 30 ms, giving a total duration of 540 ms. In this figure, only 9 frames (every second frame) are shown. There was no temporal separation between frames, and images were constantly visible during both static and dynamic primes. A short retention interval (300 ms), was then followed by a single static target image which remained visible until response. (a) An example of a DI/DE trial; (b) an example of a SI/DE trial.

More specifically, why would we expect that a matching task, rather than an old/new task, could successfully demonstrate such an advantage?

In one sense, a dynamic-prime advantage could be predicted purely on ecological grounds: in the real-world, faces move. If we believe that a task engages face-processing mechanisms, as opposed to, say, picture-processing mechanisms (eg Bruce 1982), then providing stimuli that are more like the 'real-thing' might well be expected to show some performance advantage. Such an ecological motivation is surely one of the main driving forces behind previous studies that have employed moving rather than static images of faces (eg Bruce and Valentine 1988; Knight and Johnston 1997; Lander et al 1999; Pike et al 1997; Schiff et al 1986).

However, one might also predict a dynamic-prime advantage due to the fact that moving primes deliver more task-relevant information than the static primes. That is, motion can make available a whole range of views of an object in a coherent, meaningful sequence. Moreover, such a sequence can be delivered to the visual system in a very short space of time. As we might reasonably assume that 'more' is better than 'less' information in this context, then we might also reasonably predict some form of dynamic performance advantage.

How might the visual system make use of the additional information provided by a dynamic sequence? Our working hypothesis is that objects in motion give rise to fundamentally different forms of representation than objects that neither have nor imply motion. Freyd (1987) coined the term 'dynamic mental representations' to describe such mental constructs. Using evidence from representational momentum (Freyd and Finke 1984; Hubbard 1995) and other forms of memory distortions (eg boundary extension — Intraub and Richardson 1989), Freyd (1987, 1993) has argued that the visual system might seek to maintain precise information about the way an object moves or changes. This could be achieved in a representational structure that contains temporal as well as spatial dimensions. She argued that such dynamic mental representations would be highly adaptive in a world in which we are constantly required to react to, and often anticipate, the behaviour of other moving objects.

More recently, Kourtzi and Nakayama (2001) have proposed a similar distinction between static and dynamic object representations. They found that moving, novel objects could be primed across image transformations, such as mirror reversals and changes in size, but not across temporal delays exceeding more than a few seconds. The opposite pattern was observed for objects presented statically. They suggest that a static object system might exist to mediate long-term object recognition processes while a dynamic motion-based system would be useful to continuously update information about objects for visual guidance of action.

Importantly, both in the studies of Kourtzi and Nakayama (2001) and the work of Freyd and her colleagues (eg Freyd and Johnson 1987), the effects associated with moving stimuli have been shown to occur over very brief time intervals, on the order of a few seconds at most. This time-dependence suggests that tasks designed to probe relatively short-term representations might be better suited for exploring object dynamics than tasks aimed at long-term, more permanent representations (see also Freyd 1983). Thus, the current matching task, with a prime – target stimulus onset asynchrony (SOA) of less than a second, should be well suited for exploring facial dynamics.

The aim of the current work is not, however, to try to prove that dynamic mental representations exist, or even to suggest that they are the only mechanism that could account for potential dynamic-object matching advantages. Rather, the goal of this work is to first establish whether some form of performance difference between dynamic and static stimuli can be measured within the context of a face-matching task. The concept of dynamic mental representations was introduced simply to motivate our general interest in dynamic objects, and to provide a rationale for the shift from old/new recognition tasks towards face matching. In section 5 we return to the broader issue of representation and consider other mechanisms that could underlie processing differences between dynamic and static objects.

Before that, in three experiments, we use a sequential matching task to assess whether seeing a short video clip of a smiling or frowning non-degraded, non-famous face would act as a better 'prime' than a single still image of such an expression. In experiments 1 and 2, the task was to match the identity of the people shown in the prime and target, whereas experiment 3 involved an expression-matching task. As the matching decision itself was always relatively easy, the predicted difference in performance was expected in the speed with which observers would make their judgments, rather than in a difference in error rates. Our primary interest, then, was in whether the speed of matching responses would vary as a function of prime type. Our main hypothesis was that moving primes would give rise to faster responses than static primes due to basic differences in information content.

2 Experiment 1

On each trial of this experiment, a 'prime' face appeared in the middle of the screen for 540 ms. The prime face then disappeared and the screen went blank for a 300 ms interstimulus interval (ISI). Finally a 'target' face appeared in the centre of the screen and remained visible until the participant responded. The participant was instructed to make a "same" response if they judged that the prime face and target face belonged to the same person and a "different" response otherwise.

As shown in figure 1, the crucial factor of image motion was manipulated by changing the nature of the prime face. For dynamic trials, the prime consisted of an 18-frame video sequence showing the onset of a smile or a frown. For static trials, the prime consisted of a single frame showing the end point of the smile or frown. The static primes were always identical to the final frame of one of the dynamic-prime sequences, and the duration of both types of prime was held constant at 540 ms. The second face to appear on each trial, the target face, was always a single static image. All images, both prime and target, were non-degraded; that is, they were high-quality, photographic positive, video images.

The relationship between the two faces appearing on each trial could vary across both identity and expression. These crossed factors produced four types of trial: (i) same identity/same expression (SI/SE), (ii) same identity/different expression (SI/DE), (iii) different identity/same expression (DI/SE), and (iv) different identity/different expression (DI/DE). The inclusion of expression as a factor was motivated by our desire to examine identity-matching performance across changes in non-rigid configuration, and also to allow us to explore the matching of expression using an identical set of stimuli in a subsequent experiment (see experiment 3 below).

As mentioned in section 1, our prediction was that the dynamic primes would lead to better matching performance than the static primes. As well as reflecting the basic ease of the matching decisions itself, such a focus on speed of response, rather than error rates, follows a long tradition of explicit matching studies (eg Young et al 1986; see Posner 1986 for a review), where reaction time (RT) is typically the main dependent measure.

2.1 *Method*

2.1.1 *Participants.* Nineteen University of Oregon undergraduates (thirteen female and six male) received partial course credit for participating in this experiment. All participants had normal or corrected-to-normal vision and were naïve as to the research questions under investigation. No participants had pre-experimental familiarity with the faces that were used as stimuli.

2.1.2 *Stimuli.* Eight short video clips of human models displaying naturalistic facial expressions were used as the stimuli in this experiment. Each clip lasted 540 ms and contained 18 discrete frames. Four models (two female and two male) provided two expression sequences each, one with a positive valence (smile) and one with a negative valence (frown).

Models were filmed sitting down against a uniform white background at a standard distance of approximately 3 m. Facial expressions were elicited by an interactive technique in which models attended to and responded to information presented on a video monitor just below the camera. This technique was designed to produce a range of expressions without requiring them to be posed or produced by the use of excessively shocking or disturbing material (Thornton 1994).

Lighting was designed to cast a slight shadow over the left side of the face with the key light placed up and to the right of the model and a filler light, which was bounced from a reflective umbrella, being placed to the left. A backlight was used to outline the head and shoulders, providing clear separation from the background. The key and filler lights used daylight-balanced 250 W photoflood bulbs, while the backlight was a regular 100 W, household incandescent bulb.

After filming, individual video frames were converted to gray-scale images and were apertured to reduce the influence that hair and clothing might have on identity judgments. The aperture size was an 81 pixel by 81 pixel square ($\sim$3 cm $\times$ 3 cm), which, when viewed at the standard distance of 60 cm used throughout these experiments, subtended 2.86 deg $\times$ 2.86 deg. The colour of the background surrounding the aperture was middle gray, as was the entire screen whenever stimuli were not present.

For dynamic primes, the entire 18 frames of a video sequence was used. For static primes and all target images, the final frame of one of the sequences was presented as a still image for 540 ms. A Macintosh Quadra 700 with a standard 15-inch monitor (66.7 Hz refresh rate) was used to present the stimuli.

2.1.3 *Design.* The experiment consisted of five distinct blocks of trials, with each participant completing one training block and four experimental blocks. Each block consisted of 64 trials, half of which contained dynamic primes and half of which contained static primes. Within this motion factor, there were equal numbers of same trials and different trials. 'Same' trials were constructed by exhaustively combining the image sequences for each model. For example, the model 'male 1' contributed the following prime + target sequences: male 1 smile + male 1 smile; male 1 frown + male 1 frown; male 1 smile + male 1 frown; male 1 frown + male 1 smile. Thus, an equal number of trials contained expression matches as expression mismatches. 'Different' trials were constructed by randomly selecting pairs of sequences from different models with the added constraints that within a block there must be equal numbers of expression match/mismatch and equal numbers of gender match/mismatch trials. The order of trials within each block was randomised separately for each participant on a block-by-block basis.

2.1.4 *Procedure.* Participants were seated in front of the computer screen at a standard viewing distance of 60 cm. Participants were told that each trial would involve the presentation of two faces, a prime face followed by a target face. They were instructed to pay close attention to the identity of the prime face so that they would be able to decide if the target face showed the same or a different person. Participants were told that the target face would always be a still image, but the prime face would sometimes be a short video clip (dynamic primes) and sometimes a single still frame (static primes). It was emphasised that this video/still manipulation was not relevant to the identity decision they were required to make. Likewise, it was pointed out that while the expression of the prime face and the target face would sometimes match (eg smile and smile) and sometimes mismatch (eg frown and smile), this dimension was not relevant to the task of comparing the identity of the two faces.

Participants were given 32 practice trials with an emphasis on accuracy followed by 32 practice trials with an emphasis on both speed and accuracy. Feedback was given during the second 32 practice trials in the form of a moderately loud 'beep', whenever participants made an incorrect response or took longer than 800 ms to respond. When the training phase was completed, participants were informed that they would be shown another four blocks and that the nature of the trials, the required responses, and the feedback regime would be identical to the training block. Each block consisted of 64 trials and took a little over 5 min to complete. The order of the trials within each block was completely randomised on a block-by-block basis.

2.2 *Results*

Table 1 presents a summary of both RT and accuracy data from experiment 1. The predicted difference between dynamic and static primes was only apparent for the SI/DE trials. As can be seen in figure 2, this difference took the form of an RT advantage for dynamic-prime trials ($M = 559$ ms, $SE = 9$ ms), which were responded to some 20 ms faster than static-prime trials ($M = 580$ ms, $SE = 10$ ms) ($F_{1,16} = 5.34$, $MSE = 4803$, $p < 0.05$). Accuracy for SI/DE trials was lower than for any other type of trial, although in absolute terms it remained relatively high ($M = 87\%$, $SE = 1\%$). More importantly, there was a 2% accuracy advantage for dynamic-prime trials, a trend which, while not significant, argues against a speed/accuracy trade-off explanation for the observed RT advantage.

Table 1. Experiment 1: Accuracy and reaction-time (RT) data for all types of trial organised by type of prime (standard errors are in parentheses).

Type of trial	Dynamic prime		Static prime	
	RT/ms [a]	% corr [b]	RT/ms [a]	% corr [b]
SI/SE	521 (8)	94 (1)	523 (8)	96 (1)
SI/DE	559 (9)	88 (1)	580 (10)	86 (1)
DI/SE	591 (7)	90 (2)	594 (7)	90 (1)
DI/DE	587 (7)	90 (2)	586 (7)	91 (2)

[a] Median RT. [b] Percent correct.

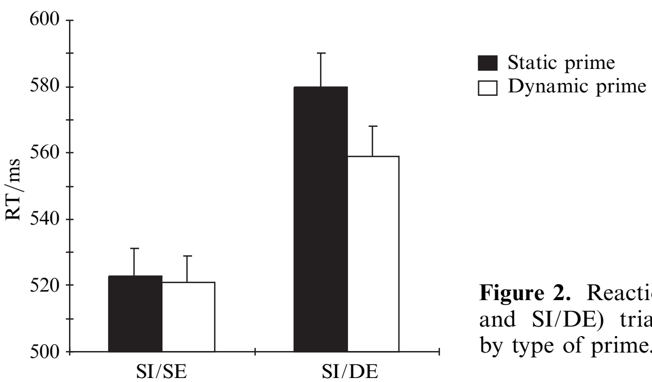

Figure 2. Reaction time (RT) for 'same' (SI/SE and SI/DE) trials from experiment 1, organised by type of prime.

Responses to the other type of 'same' trial, SI/SE, were generally faster ($F_{1,17} = 23.8$, $MSE = 7420$, $p < 0.001$), and more accurate ($F_{1,17} = 27.18$, $MSE = 0.0179$, $p < 0.001$), than responses to SI/DE trials. However, there was no significant RT difference between dynamic-prime and static-prime trials for this type of trial. While there was a slight trend in the predicted direction, accuracy data showed the opposite effect, with a significant 2% advantage for static-prime trials over dynamic-prime trials ($F_{1,18} = 5.32$, $MSE = 0.035$, $p < 0.05$).

Analysis of trials requiring a different response revealed no significant differences between dynamic and static primes either for RT or accuracy. A direct comparison of the two types of different trials revealed only one significant difference, with responses to DI/SE trials being generally slower than responses to DI/DE trials ($F_{1,17} = 9.24$, $MSE = 1175$, $p < 0.01$).

As the current experiment was designed with four repeated blocks, it was possible to examine how the pattern of results altered as participants became more familiar with the stimuli and the task. Importantly, this analysis revealed no interactions between block and type of prime. That is, the observed RT advantage for dynamic primes in SI/DE trials was present in all four blocks and the absence of prime differences in any other type of trial was also consistent across blocks.

There were, however, clear indications that general performance improved as the experiment progressed. There was a marginal increase in accuracy across block for both types of same trial ($F_{3,51} = 2.66$, $MSE = 0.009$, $p = 0.6$), and significant RT decreases for both same ($F_{3,51} = 3.30$, $MSE = 7964$, $p < 0.05$) and different trials ($F_{3,51} = 2.91$, $MSE = 4875$, $p < 0.05$). There were no other main effects or interactions involving block.

As the set of facial stimuli was very small in the current experiment, an analysis of item effects was conducted to ensure that a single face was not unduly influencing the pattern of results. While some pairs of faces and some expressions did appear to be matched more quickly, the pattern of facilitation was equal for both static and dynamic images. That is, there were no interactions between type of prime and specific faces or expressions.

2.3 *Discussion*

The results of experiment 1 provide some initial evidence that motion can influence the speed of matching responses. The finding of a 21 ms advantage for dynamic-prime trials over static-prime trials is consistent with our hypothesis that performance in this task engages representational mechanisms that capitalise on the additional information contained in the dynamic-prime sequences. However, in order to better understand this apparent enhancement, what needs to be explained is why the observed advantage only appears for SI/DE trials.

It is perhaps not surprising that motion had no influence on trials in which the two faces showed completely different people. This suggests that, in the current paradigm, motion is not affecting general levels of arousal or alertness. That is, seeing something move or change does not always increase the speed or accuracy of subsequent responses. Rather, motion appears to have some influence on the processing of a *specific* face. In experiment 3, we further explore this notion of specificity by using the same set of stimuli, but requiring responses based on expression matching rather than identity matching.

Of the two types of trial in which the prime and the target image show the same person, only one type, SI/DE, showed a significant RT advantage. Previous memory research has found that facial motion only appears to make a difference to performance if viewing conditions are suboptimal in some way. For instance, Knight and Johnston (1997) and Lander et al (1999) could only find recognition advantages for images that were severely degraded. In the current experiment, while all images were of equal quality, SI/DE trials are probably the most taxing of trials, in that they require generalisation across different views (ie expressions) of the same face. This difficulty is reflected in the overall level of speed and accuracy for this type of trial, which is lower than for any of the other three types. It is thus possible that dynamic information is more useful in SI/DE trials owing to an increase in processing demands.

Similarly, the lack of a prime effect for the other type of 'same' trial, SI/SE trials, could be related to the ease with which matching decisions can be made. This is particularly true for static trials, as the target item is physically identical in all respects to the preceding prime. Such identical-picture matching generally leads to very fast and very accurate responses (Bruce 1982; Vokey and Read 1992), which could well have overpowered potential dynamic influences. Indeed, responses to dynamic primes for this type of trial were also speeded relative to SI/DE trials, suggesting some advantage from the physical match between the last video frame and the target. Experiment 2, below, addressed this possibility by eliminating physical-match confounds.

Previous research using recognition paradigms (eg Christie and Bruce 1998) has suggested that the role of motion may change as a face becomes more familiar. It is interesting to note that in our paradigm there appeared to be no interaction between experimental block and type of prime. That is, there was no increase or decrease in the size of the dynamic advantage as participants were repeatedly shown the same faces. As our design presented equal numbers of static and dynamic versions of every face, the observed advantage appears to arise as an immediate consequence of priming on a given trial. Familiarity with a face, at least within the range studied here, does not seem to modulate the effect.

In summary, the results of experiment 1 seem to be consistent with the idea that motion can lead to a representational advantage for immediate matching, at least when the match involves some form of generalisation across successive views of the same face. In experiment 2 we provide a further test of this idea before going on to examine whether motion can still influence processing of a face when the task is directed away from the representations underlying identity of a face and on to the more abstract representation of expressions.

3 Experiment 2

In experiment 1 there were some trials in which the prime and target images were physically identical. We speculated that on such trials, picture matching rather than face processing might dominate performance (Bruce 1982). Such physical matching might explain why SI/SE trials (in which prime and target were always identical) failed to show any influence of prime motion, while SI/DE trials (in which the prime and target were always physically different) produced a dynamic advantage. To eliminate the picture-matching problem, we ran a second experiment with the same design as the first except that all *target* images were now rotated 180° in the picture plane (Yin 1969). This manipulation meant that, on every trial, participants had to match an upright prime image (either static or dynamic) to an inverted static target. As generalisation from upright to inverted views was required on every trial, this experiment also provides a test of the claim that motion might be most useful when a match involves some form of generalisation across views of the same object. We predicted that, under such conditions, both types of 'same' trial would display RT advantages for dynamic-prime over static-prime trials.

In addition to removing the physical match between prime and target images and enforcing some level of generalisation on every trial, the facial-inversion manipulation also increases the overall difficulty of the matching task. That is, processing an upside-down face is generally harder than processing a normal face. It is thought that faces are particularly prone to inversion effects because they rely to a large extent on configurational processing (eg Farah et al 1995; Rhodes et al 1993; Valentine and

Bruce 1988).[2] As previous researchers (eg Knight and Johnston 1997; Lander et al 1999) have suggested that facial motion may be particularly useful when task demands are high, we also predicted that the size of the observed dynamic-prime advantage would increase relative to those observed in experiment 1.

3.1 *Method*

3.1.1 *Participants.* Twenty-four students from the University of Oregon participated in this experiment for partial course credit. All participants had normal or corrected-to-normal vision and were naïve as to the research questions under investigation. There were sixteen female and eight male participants. No participants had taken part in experiment 1 and none had pre-experimental familiarity with the faces that were used as stimuli.

3.1.2 *Stimuli and design*. The equipment, stimuli, and basic design of this experiment were identical to those used in experiment 1. The only change was that in experiment 2 all target images were rotated by 180° in the picture plane, that is they were shown upside-down.

3.1.3 *Procedure*. The basic training and testing procedures were also identical to experiment 1. Participants were shown four blocks of experimental trials, each consisting of 64 trials. Hand of response was counterbalanced across participants and, as before, the order of trials within a block was completely randomised separately for each participant.

3.2 *Results*

Table 2 presents a summary of RT and accuracy data from experiment 2. The RT advantage for dynamic-prime images is now apparent for both types of 'same' trials (see figure 3). For SI/SE trials this 17 ms dynamic-prime ($M = 560$, $SE = 8$) over static-prime ($M = 577$, $SE = 8$) advantage ($F_{1,23} = 5.02$, $MSE = 5071$, $p < 0.05$) was accompanied by a general drop in speed and accuracy as compared to experiment 1. For SI/DE trials, there was very little impact of target inversion on overall speed and accuracy and the 16 ms dynamic-prime ($M = 578$, $SE = 8$) over static-prime ($M = 594$, $SE = 8$) advantage was again highly consistent ($F_{1,23} = 6.17$, $MSE = 3385$, $p < 0.05$). As in experiment 1, there were no reliable dynamic-prime advantages in accuracy data for either type of same trial.

Table 2. Experiment 2: Accuracy and reaction-time (RT) data for all types of trial organised by type of prime (standard errors are in parentheses).

Type of trial	Dynamic prime		Static prime	
	RT/ms [a]	% corr [b]	RT/ms [a]	% corr [b]
SI/SE	560 (8)	88 (1)	577 (8)	88 (2)
SI/DE	578 (8)	83 (2)	594 (8)	84 (2)
DI/SE	593 (7)	82 (2)	599 (6)	85 (2)
DI/DE	582 (7)	85 (2)	591 (7)	83 (2)

[a] Median RT. [b] Percent correct.

Despite a general decrease in performance for SI/SE trials, responses to these trials were still generally faster ($F_{1,23} = 7.46$, $MSE = 5960$, $p < 0.05$) and more accurate ($F_{1,23} = 11$, $MSE = 0.0165$, $p < 0.01$), than responses to SI/DE trials. Analysis of trials requiring a different response showed that responses to DI/DE trials were generally faster ($F_{1,23} = 5.87$, $MSE = 1671$, $p < 0.05$), but not more accurate ($F_{1,23} = 0.81$,

[2] Objects other than faces will show a similar inversion effect to the extent that they rely on configurational coding, either through the influence of expertise (Diamond and Carey 1986) or experimental manipulation (Farah et al 1995; Gauthier and Tarr 1997; Rhodes et al 1993).

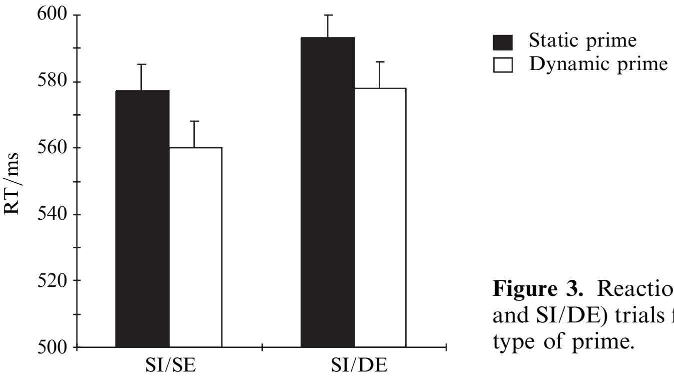

Figure 3. Reaction time (RT) for 'same' (SI/SE and SI/DE) trials from experiment 2, organised by type of prime.

$MSE = 0.01$, $p = 0.38$), than to DI/SE trials. There were no other significant effects involving different trials.

As in experiment 1, there was considerable evidence that overall performance improved as participants became more familiar with the task and the faces. For 'same' trials, there was a main effect of block, both for accuracy ($F_{3,66} = 3.88$, $MSE = 0.019$, $p < 0.05$) and RT ($F_{3,66} = 5.55$, $MSE = 9206$, $p < 0.01$). For 'different' trials, there was a significant main effect of block for accuracy ($F_{3,66} = 10.59$, $MSE = 0.024$, $p < 0.001$), but only a marginal effect for RT ($F_{3,66} = 2.46$, $MSE = 7400$, $p = 0.07$). More importantly, however, there were no interactions involving block and type of prime, suggesting that the observed dynamic advantage is not a function of familiarity. Similarly, there were no interactions between specific faces/expressions and the type of prime across any of the four types of trial.

3.3 *Discussion*

The results of experiment 2 provide further evidence that moving faces and static faces can give rise to different behavioural consequences. Unlike in experiment 1, the observed RT advantage for dynamic faces was present whenever the prime and target images showed the same person. The observation of this same identity effect, together with the complete absence of prime effects for different trials, also lends further support to the idea that motion may be serving to enhance person specific representations, rather than having a general alerting or arousing effect.

While the introduction of 180° rotated target faces appears to have eliminated the effects of picture matching on the SI/SE trials, it did not increase the magnitude of the observed dynamic-prime advantage. We had predicted such an increase on the basis of previous research suggesting the influence of facial motion might be felt most strongly when task demands were high (eg Knight and Johnston 1997; Lander et al 1999). However, the magnitude of the dynamic-prime advantage for SI/DE trials actually shrank a little, from an initial level of 21 ms in experiment 1 to 17 ms in experiment 2. One possibility for the lack of an increase was simply that the matching task places an upper limit on the size of observable differences between static-prime and dynamic-prime trials. Another possibility is that inverting the target images did not make the general task of matching that much more difficult than in experiment 1.

As mentioned above, there is widespread agreement in the literature that rotating faces impairs our ability to use configural-processing strategies. However, there is still some debate about whether observed performance decrements reflect a qualitative shift in processing (ie away from configural processing towards a more feature-based approach) or simply a slowing down of those processes, that is a quantitative shift (Valentine and Bruce 1988). Behavioural and physiological evidence exists supporting both the qualitative account (eg Jeffreys 1993; Sarfaty et al 1992; Tanaka and Sengco

1997) and the quantitative account (eg Kanwisher et al 1998; Perrett et al 1988; Valentine and Bruce 1988). While the fairly subtle decrements observed in experiment 2 seem more consistent with a quantitative account, the current data cannot rule out the operation of highly efficient feature-based systems.

The use of inverted target images, and the debate surrounding how such images may be processed, raises the issue of whether tasks employing inverted stimuli can really be considered measurements of 'face processing'. However, in the current experiment, it was only the target images that were inverted. The static and dynamic prime images, the main focus of the study, remained correctly oriented, as in experiment 1. Thus, even if there are questions concerning the validity of inverted images, experiment 2 would only be reduced to comparing how dynamic versus static faces can be matched to non-face (inverted) images.

The question of what happens to moving inverted faces versus static inverted faces has been explored in the face-memory literature. Knight and Johnston (1997) found no difference between the recognition of moving versus static inverted images of famous people. In contrast, Lander et al (1999) were able to demonstrate an advantage for moving inverted faces in two experiments with a very similar design to that of Knight and Johnston (1997). It is not immediately clear why the results of these experiments should be so different. We hope that future studies exploring the impact of inverted prime images in the current paradigm may shed further light on this issue.

4 Experiment 3

In experiments 1 and 2 we used an identity-matching task to show that moving faces can speed matching responses relative to static faces. This advantage was observed whenever identity was constant across prime and target faces and picture matching was not available as an alternative strategy. This pattern of facilitation for non-degraded, non-rigid facial motion has been very hard to demonstrate with traditional long-term-memory recognition tasks (eg Bruce and Young 1986; Christie and Bruce 1998). This suggests that motion may be particularly effective during the processing of the more temporary, working-memory representations thought to underlie performance during matching. In this final experiment we explore whether a similar dynamic advantage can be observed when the matching dimension is shifted from facial *identity* to facial *expression.*

In experiment 3, a "same" response was required whenever two images depicted the same facial expression rather than the same facial identity. Observers were shown exactly the same stimuli as in experiment 1,[3] but the mapping of responses to pairs of images was changed. That is, observers saw the same set of four trial types, namely (i) SI/SE, (ii) SI/DE, (iii) DI/SE, and (iv) DI/DE, but were now instructed to respond "same" if the two images showed the same expression (ie trial types 1 and 3) and "different" otherwise (ie trial types 2 or 4).

Changing the dimension of matching from identity to expression while keeping the physical stimuli constant should provide useful evidence about the nature of the dynamic-prime advantage observed in experiments 1 and 2. For instance, if the SI/DE trials are still the only type of trial to show a dynamic-prime advantage (even though they now map to a "different" response), this would suggest that the effect relies heavily on some form of object-specific representation. That is, an advantage will be observed whenever a prime and the target have some basic level of object correspondence.[4]

[3] We did not replicate experiment 2 as it is less clear from the literature how expression processing interacts with facial inversion.

[4] While a SI/DE match might also suggest some form of image sequence artifact (eg the start of the dynamic sequences might be similar to the static targets), the results of experiment 2, where both types of trial showed a dynamic-prime advantage, make this sort of explanation seem unlikely.

The appearance of a dynamic-prime advantage for any other types of trial may help to shed further light on the relationship between identity and expression processing. There is now considerable evidence, from both behavioural and neuropsychological studies to suggest that facial-identity and facial-expression processing takes place separately and in parallel (eg Bruce and Young 1986; Humphreys et al 1993; Young et al 1986).[(5)] Do these systems process information in similar ways? Experiments 1 and 2 suggest that during the matching of identity, motion is recruited when some form of generalisation is required. When matching expression, is it possible that the need to generalise across identity leads to a dynamic-prime advantage? A direct analogy would predict that such an advantage would appear for DI/SE trials.

Finally, a failure to find any difference between static and dynamic primes while matching facial expression would suggest that the previously observed advantages reflect an interaction between object-specific representations and the nature of the specific matching task.

4.1 *Method*

4.1.1 *Participants.* Thirty-six students from the University of Oregon participated in this experiment for partial course credit. All participants had normal or corrected-to-normal vision and were naïve as to the research questions under investigation. There were twenty-five female and eleven male participants. No participant had taken part in experiment 1 or 2 and none had pre-experimental familiarity with the faces that were used as stimuli.

4.1.2 *Stimuli and design.* The equipment, stimuli, and basic design of this experiment were identical to those used in experiment 1. The only difference was in the response mapping. Specifically, participants were told to match the depicted expression shown on the prime and target faces rather than the identity. Thus they were told to respond "same" to SI/SE trials and DI/SE trials and to respond "different" to SI/DE trials and DI/DE trials.

4.1.3 *Procedure.* The basic training and testing procedures were also identical to those in experiment 1. In total, participants were shown four blocks of experimental trials, each consisting of 64 trials. Hand of response was counterbalanced across participants and, as before, the order of trials within a block was completely randomised separately for each participant.

4.2 *Results*

Table 3 presents a summary of RT and accuracy data. Unlike in experiments 1 and 2 there was no overall RT difference between dynamic and static primes for any of the four types of trial. Examination of DI/SE trials, however, does reveal a 17 ms trend in the direction of a dynamic-prime advantage. While this trend was non-significant ($F_{1,28} = 1.78$, $MSE = 10673$, $p = 0.19$), it must be evaluated in the context of significant prime-type × identity × expression interaction ($F_{3,84} = 4.41$, $MSE = 728291$, $p < 0.01$). Examination of this effect revealed that for two, out of the possible eight, prime images dynamic responses were considerably faster than static responses ($M = 76$ ms). The remaining six prime sequences showed a small trend in the opposite direction ($M = 8$ ms). Such item effects were not present in experiments 1 and 2. Accuracy data for DI/SE trials showed a consistent effect of prime, however static images

[(5)] Indeed, it is possibly due to this dissociation that the role of motion during identity processing has received so little attention. Motion is clearly a vital part of expression processing, as it is for other non-identity aspects of information extraction on the face, such as visible speech (eg Campbell et al 1996a, 1996b). The discovery of separate processing systems for such non-identity information appears to have led to the false assumption that motion cannot also be important for solving identity-related tasks.

Table 3. Experiment 3: Accuracy and reaction-time (RT) data for all types of trial organised by type of prime (standard errors are in parentheses).

Type of trial	Dynamic prime		Static prime	
	RT/ms [a]	% corr [b]	RT/ms [a]	% corr [b]
SI/SE	568 (7)	90 (1)	564 (8)	93 (1)
SI/DE	619 (7)	88 (1)	619 (6)	91 (1)
DI/SE	617 (9)	80 (2)	630 (9)	84 (2)
DI/DE	626 (7)	89 (1)	627 (7)	90 (1)

[a] Median RT. [b] Percent correct.

($M = 84\%$, $SE = 2$) led to more accurate responses than dynamic images ($M = 80\%$, $SE = 2$) ($F_{1,35} = 4.67$, $MSE = 3.2$, $p < 0.05$).

Responses to the other type of same trial—SI/SE—were both faster ($F_{1,35} = 74.6$, $MSE = 5044$, $p < 0.001$) and more accurate ($F_{1,35} = 65.8$, $MSE = 2.7$, $p < 0.001$) than responses to DI/SE trials. This difference between the two types of same trial was also found in experiment 1, and almost certainly reflects the contribution of identical-picture matching. Consistent with this picture-matching explanation, responses to static primes were some 3% more accurate than to dynamic primes for SI/SE trials ($F_{1,35} = 4.32$, $MSE = 2.1$, $p < 0.05$). While there were also prime × identity ($F_{3,105} = 7.14$, $MSE = 1.6$, $p < 0.001$), prime × expression ($F_{1,35} = 12.77$, $MSE = 2.0$, $p < 0.01$), and prime × identity × expression ($F_{1,105} = 8.39$, $MSE = 1.5$, $p < 0.001$) interactions, all of these effects reflected changes in the magnitude of the static-prime advantage, rather than the appearance of an item-specific dynamic-prime advantage. More specifically, there were no instances where dynamic primes led to more accurate responses. Analysis of the RT data for SI/SE trials revealed no main effects or interactions involving type of prime.

Analysis of different responses revealed no RT effects based on the type of prime, either for SI/DE or DI/DE trials. Accuracy data for SI/DE trials did show a sensitivity to the type of prime, but again this reflected an advantage for static ($M = 91\%$ $SE = 1.7\%$) over dynamic ($M = 88\%$, $SE = 1.9\%$) primes ($F_{1,35} = 5.89$, $MSE = 2.0$, $p < 0.05$). There was also a marginal prime × identity × expression interaction ($F_{3,105} = 2.68$, $MSE = 1.6$, $p = 0.051$), with one particular prime image showing a larger than average static advantage. Accuracy data for DI/DE trials showed no main effect of prime, but there was again an item effect, with only one of eight prime images showing a strong dynamic advantage ($F_{3,105} = 3.47$, $MSE = 1.9$, $p < 0.05$). A direct comparison between the two types of different trials revealed no significant differences either in terms of RT or accuracy.

Overall, responses on trials with smiling-prime images were faster and more accurate than responses with frowning-prime trials. While this pattern may have been influenced by the item-specific effects mentioned above, table 4 illustrates that this smiling advantage was highly consistent, appearing even for trial types in which such item effects were completely absent. There was only one instance of a prime × expression interaction (accuracy data for SI/SE trials) and this took the form of a static advantage, suggesting that motion has little overall effect on this smiling-face advantage.

Finally, as in experiments 1 and 2 there were consistent learning effects which did not interact with type of prime. Specifically, there were main effects of block for same trials, both for RT ($F_{3,105} = 6.39$, $MSE = 10157$, $p < 0.001$) and accuracy ($F_{3,105} = 3.5$, $MSE = 1.1$, $p < 0.05$). Similarly, responses to different trials showed main effects of block for RT ($F_{3,105} = 7.2$, $MSE = 13573$, $p < 0.001$) and accuracy ($F_{3,105} = 3.37$, $MSE = 1.7$, $p < 0.05$).

Table 4. Experiment 3. Accuracy and reaction-time (RT) data for smiling versus frowning prime image organised by type of trial (standard errors are in parentheses).

Type of trial	Frown		Smile		Difference	
	RT/ms [a]	% corr [b]	RT /ms [a]	% corr [b]	RT/ms [a]	% corr [b]
SI/SE	620 (7)	87 (1)	512 (5)	98 (1)	***	***
SI/DE	664 (6)	81 (1)	575 (5)	97 (1)	***	***
DI/SE	697 (9)	67 (2)	550 (6)	97 (2)	***	***
DI/DE	675 (7)	83 (1)	577 (5)	96 (1)	***	***

[a] Median RT. [b] Percent correct. ***$p < 0.001$.

4.3 *Discussion*

In experiment 3, we used exactly the same set of stimuli and organisation of trials, but changed the nature of the matching task from identity to expression. This task manipulation appears to have eliminated the consistent dynamic-prime advantage found in experiments 1 and 2. When there were consistent differences between static and dynamic prime images in the current experiment, these generally took the form of a static-prime advantage.

An important implication of this experiment is that the appearance of a dynamic-prime advantage in face processing appears to be sensitive to both stimulus characteristics (ie objects must match) and task demands (ie observers must be matching the objects, not features of the objects). Alternatively, the lack of a dynamic-prime advantage could reflect some fundamental difference in information processing within the expression-processing and identity-processing streams (Bruce and Young 1986). However, given the small set of stimuli used in the current experiment and the appearance of a number of item effects, these conclusions can only be offered as initial impressions. Further studies, particularly with larger sets of stimuli, will be required before the role of motion in expression processing can be more fully understood.

Even given the appearance of item effects, however, one clear pattern that did emerge was a striking difference in performance between smiling and frowning faces (see table 4). This happy-face advantage has been noted frequently in the face literature (eg Calder et al 1997; Kiouac and Doré 1983; Kirita and Endo 1995; Ladavas et al 1980). A number of explanations have been put forward to explain this phenomenon, including changes in transmission rates for information at different spatial scales (ie smiles are defined in lower spatial frequencies, frowns in higher spatial frequencies) and differences in processing mode (ie smiles engage holistic processing, frowns analytic processing), but as yet there is no definitive answer (see Kirita and Endo 1995). The current work does little but confirm the existence of this happy-face advantage, although clearly our results suggest that the addition of motion does little to add or subtract from the basic effect.

5 General discussion

In a series of three experiments, we used an immediate matching task to demonstrate that responses to human faces can be facilitated by the presence of motion. This facilitation takes the form of an RT advantage for moving over static-prime images and was observed for identity comparisons whenever generalisation across expression (experiment 1) or view (experiment 2) was required. Using identical stimuli, we did not find a similar advantage for expression matching (experiment 3). It is interesting to note that motion did not provide a general alerting or arousing advantage, but rather facilitated performance only when the prime and target images mapped on to the same basic object (ie a particular person) and the task was specifically focused on this identity relationship.

The identity advantage observed in experiments 1 and 2 represents the first demonstration of a reliable difference between dynamic and static images of non-degraded, expressive faces. Previous researchers, using similar non-rigid motion sequences, were unable to find dynamic/static differences unless the stimuli were degraded images of famous faces (eg Bruce and Valentine 1988; Christie and Bruce 1998; Knight and Johnston 1997; Lander et al 1999). We suggest that the success of the current approach lies in shifting the nature of the task from face recognition to face matching. While the observed advantage is admittedly rather modest (ie a speed difference of around 20 ms), we believe that future studies that retain the shift of focus from recognition to matching will be able to provide new insights into the role of facial dynamics.

As discussed in section 1, we believe the shift in tasks is important in the current context because matching places more emphasis on working-memory representations than on the long-term representations typically thought to underlie old/new recognition performance. However, we do not mean to imply that dynamics are completely irrelevant for long-term representations. Patterns of 'characteristic motion' associated with a particular individual can clearly influence identification performance (eg Hill and Johnston 2001; Knappmeyer et al 2001; Lander et al 1999). The need for such patterns to develop over time means they can only be explored by tasks designed to probe long-term memory. Indeed, we cannot completely rule out the contribution of such long-term effects in the current studies. That is, participants were given repeated exposure to the same four faces. However, the absence of prime $\times$ block interactions suggests that more permanent representations of the four model faces are not exerting a significant influence on the matching performance. That is, effects of characteristic motion, such as those suggested by Christie and Bruce (1998), might have been expected to produce some modulation of the dynamic-prime advantage as the experiment progressed. As the size of the effect did not significantly vary across block, there is little evidence for the influence of such familiarity effects in the current set of data.[6]

Rather than patterns of characteristic motion, the current dynamic advantage probably reflects what Lander and Bruce (2000) called the 'generalised benefit' of viewing moving faces. That is, a direct representational advantage due to an increase in task-relevant information—multiple views in a coherent, timed sequence—relative to viewing static images. Following the work of Freyd (eg 1987) and Kourtzi and Nakayama (2001), we argue that such additional information may be captured in short-lived, 'dynamic' representations. The primary role of such representations is thought to be the visual guidance of on-going actions, and this, together with the brief temporal range over which they have been found to operate, suggests the involvement of working, rather than long-term, memory systems.

While the current findings are clearly consistent with this notion of dynamic representations, they do not, however, provide direct evidence that such mechanisms are responsible for the observed performance advantages. What other mechanisms might the visual system employ to take advantage of the additional information in the dynamic primes?

One possibility is that motion could link the various views contained in a dynamic prime via a generic temporal-association mechanism. Influential physiological studies by Miyashita (1988, 1993) have shown that individual neurons in primate temporal lobes can change their selectivity to respond to initially non-preferred images if these images frequently appear in close temporal proximity to other preferred stimuli. Inspired by these findings, Wallis and Bülthoff (2001) and Wallis (2001) have shown that human performance on face-discrimination and face-matching tasks can also be affected by the

[6] One way that long-term memory could be excluded would be to use completely new faces on each trial. We are currently in the process of collecting the large corpus of moving-face stimuli needed for such a design.

spatiotemporal association of views during learning. Other recent computational (eg Edelman and Weinshall 1991; Foldiak 1991; Wallis and Rolls 1997) and behavioural (eg Sinha and Poggio 1996; Stone 1998; Stone and Harper 1999; Wallis 1998) studies also indicate that temporal correlations, such as those associated with motion, can affect the long-term representation of objects (see Wallis and Bülthoff 1999, for a review).

Another possible way in which motion might have been used to exploit the dynamic primes is by enhancing the available structural information. That is, the extra information in the dynamic primes might give rise to better assessments of the 3-D structure of the face than static primes. A similar argument has previously been made in connection with rigid rotations of the head (Pike et al 1997). As 3-D information has been shown to improve recognition performance (eg Bruce and Langton 1994; Kemp et al 1996), it might also have an impact in the current matching task.

Clearly, future research will be needed to more clearly establish the nature of the dynamic-prime advantage observed with the current matching task, thus providing firmer ground for distinguishing between potential mechanisms. Varying the prime – target ISI might be one useful manipulation, as any effect based on dynamic representations should disappear quite quickly as ISI increases beyond a few seconds. It would also be interesting to see if the observed matching advantages can be found with other types of motion or change, for example rigid head rotations, visible speech, or other meaningful (eg morphing) or non-meaningful (eg warping) facial deformations. A pure 'temporal-association' mechanism should be affected very little by the nature of the presented sequence (Miyashita 1993). Similarly, future studies could also compare matching performance with different types of non-face objects. The pattern of results found with other biological (eg human, animal, or plant movements) and/or non-biological (eg machine parts or novel random patterns) dynamic objects, would shed light on the specificity of the current matching advantage. Such comparisons might make a useful contribution to the ongoing debate on whether faces are afforded 'special' status by the visual system (eg Diamond and Carey 1986; Farah et al 2000; Gauthier and Logothetis 2000; Gauthier and Nelson 2001; Kanwisher et al 1997; Yin 1969).

Throughout this paper an assumption has been made that motion sequences might lead to performance advantages because they increase the total information provided about a face, relative to a single static image. We share the view expressed by Lander and Bruce (2000) that such additional information might include not only the extra static views contained within the motion sequence, but also purely 'dynamic' information arising from a specific spatiotemporal pattern. In previous studies of facial motion (eg Bruce and Valentine 1988; Lander et al 1999; Pike et al 1997) attempts have been made to assess whether increasing static information alone, that is in the absence of motion, would also lead to performance advantages. This is typically done by including multiple-still control conditions. In general, whenever a dynamic-prime advantage has been found, it has not been attributable to differences in static information content (eg Lander et al 1999; Pike et al 1997). In the current work we chose not to include multiple static-face controls, as our matching task involved very brief, very precisely timed trials in which it would have been difficult to present additional static information in the absence of motion.[7] Clearly, this makes us unable to separately assess the effects of static and dynamic information increase without changing the nature of the task.

However, it would be possible to manipulate either the duration or the coherence of the dynamic sequence. If differences in information change-over-time is at the heart

[7] For example, the only way to present a sequence of more than one static image within the space of 500 ms would be by adding some form of inter-item mask. Without this, some form of apparent motion would almost certainly be observed, unless the speed of image presentation was greatly reduced. Such changes, or the use of spatially non-overlapping items, would almost certainly change the nature of the task.

of the current effect, then, at least up to some capacity limitation, we should expect to observe an increase in the performance advantage for dynamic primes as the sequence length grows. Changing the coherence of the sequence, for instance by randomising the order of the animation frames might also shed light on the basis of the observed dynamic-prime advantage. Lander and Bruce (2000) recently showed significantly better recognition performance for coherent versus scrambled movies of degraded famous faces, and Wallis (2001) likewise found that spatiotemporally ordered sequences, but not unordered sequences of rotating heads, could modulate subsequent discrimination performance. These results are consistent with findings from representational momentum, where only coherent sequences of implied motion give rise to the typical dynamic anticipation effects (Kelly and Freyd 1987). It would thus be interesting to see if the current matching advantage still occurs when the prime sequence consists of a random temporal sequence of images.

In conclusion, we believe the current work represents an important step forward in the study of facial motion. Shifting the emphasis away from standard long-term-memory recognition paradigms towards a sequential-matching task has allowed us to demonstrate a reliable difference between the processing of static and dynamic facial images. Future work will hopefully allow us to more fully explore the mechanisms that underlie these differences.

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