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Motion can amplify the face-inversion effect

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The face-inversion effect (FIE) refers to increased response times or error rates for faces that are presented upside-down relative to those seen in a canonical, upright orientation. Here we report one situation in which this FIE can be amplified when observers are shown dynamic facial expressions, rather than static facial expressions. In two experiments observers were asked to assign gender to a random sequence of un-degraded static or moving faces. Each face was seen both upright and inverted. For static images, this task led to little or no effect of inversion. For moving faces, the cost of inversion was a response time increase of approximately 100 ms relative to upright. Motion thus led to a disadvantage in the context of inversion. The fact that such motion could not be ignored in favour of available form cues suggests that dynamic processing may be mandatory. In two control experiments a difference between static and dynamic inversion was not observed for whole-body stimuli or for human-animal decisions. These latter findings suggest that the processing of upside-down movies is not always more difficult for the visual system than the processing of upside-down static images.

Key words:*Face, Motion, Inversion, Gender*

When facial stimuli are shown upside-down, human observers have difficulty extracting useful information from them (Goldstein, 1965; Hochberg & Galper, 1967; Thompson, 1980; Yin, 1969). While the processing of other objects can also be affected by misorientation (e.g., Ashworth, Vuong, Rossion, & Tarr, 2008; Diamond & Carey, 1986; Reed, Stone, Bozova, & Tanaka, 2003; Rock, 1974; Sumi, 1984), it is the disproportionate impact of inversion on faces that has fuelled interest for over 40 years (Yin, 1969; for reviews see Maurer, Le Grand & Mondloch, 2002; Rakover, 2002; Rossion, 2008; Valentine, 1988). This "face-inversion effect" (FIE) has become one of the standard tools for exploring face processing, in particular the roles of configural/relational versus feature-based mechanisms (Leder & Bruce, 2000; Rakover, 2002; Goffaux & Rossion, 2007). Much more controversially, the FIE is also often held up as a "robust marker" of the "special" status of faces (Yovel & Kanwisher, 2005; cf Ashworth et al., 2008, Rossion & Gauthier, 2002).

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Behaviourally, the FIE is measured in terms of increased response times or error rates for faces that are presented upside-down relative to those seen in a canonical, upright orientation. Such behavioural deficits have been demonstrated using a range of experimental tasks, including standard old/new recognition (e.g, Yin, 1969, Scapinello & Yarmey, 1970), concurrent matching (e.g., Kemp, McManus, & Pigott, 1990), sequential matching (e.g., Valentine & Bruce, 1988) and expression processing (e.g., Thompson, 1980; Valentine & Bruce, 1985). Neurally, the FIE has been associated with reduced fMRI activation in the fusiform face area (FFA, e.g., Yovel & Kanwisher, 2005), delayed and enhanced N170 ERP components (e.g., Rossion et al., 2000) and enhanced synchronicity in gamma band EEG activity (e.g., Anaki, Zion-Golumbic, & Bentin, 2007).

In the current paper we describe one situation in which the behavioural deficits associated with the FIE can be amplified by the presence of motion. Specifically, when observers made speeded gender classification decisions to non-degraded, full-colour stimuli, their reaction times were most noticeably slowed when the faces were both inverted *and* moving. In two separate experiments, performance on upright trials was not affected by the presence of this type of motion. When turned upside-down, responses to moving faces were on average 100 ms slower than the static baseline.

This dynamic amplification is potentially interesting for several of reasons. First, facial motion typically improves, or at worst does not affect, performance relative to static baseline conditions (see O'Toole, Roark, & Abdi, 2002 for a review). This is true both for rigid movements of the whole head, and also the non-rigid deformation associated with facial expression, which is the type of movement used in the current work. Second, this dynamic disadvantage occurs in a situation in which form cues remain fully available at all times. Motion appears to be interfering with performance, but cannot be ignored. Finally, in two control experiments, we could find no evidence that other complex biological stimuli were similarly affected by dynamic inversion. This was true even though one class of stimuli, human bodies, do show an inversion effect (e.g., Reed et al., 2003; Sumi, 1984). With bodies, the size of the static and dynamic inversion effects was identical.

EXPERIMENT 1

In our first experiment we asked participants to make speeded gender classification decisions to non-degraded images of faces that were either static or moving (see Figure 1). Gender categorization has been used in many experimental settings (e.g., Brown & Perrett, 1993; Bruyer, Galvez & Prairial, 1993; Campbell, Benson, Wallace, Doesbergh, & Coleman, 1999; Mouchetant-Rostaing, Giard, Bentin, Aguera, & Pernier 2000; Nestor & Tarr, 2008a; Yamaguchi, Hirukawa, & Kanazawa, 1995) as male/female decisions can be made quickly and accurately, even when a face has never been seen before (although see Rossion, 2002). There is still some debate as to the sources of information that underlie such gender decisions. Some studies have stressed local features, such as the eyes, chin or mouth (e.g., Brown & Perrett, 1993; Russell, 2003; Schyns, Bonnar, & Gosselin, 2002; Yamaguchi et al., 1995). Others have suggested relational properties between features, such as the eyebrow and upper eyelid (Burton, Bruce, & Dench, 1993; Campbell et al., 1999) or more global properties, such as the overall shape of the face (e.g, Baudouin & Humphreys, 2006; Bruyer et al.,1993; Stevenage & Osborne, 2006) or skin tone (e.g., Bruce & Langton, 1994; Hill, Bruce, & Akamatsu, 1995; Nestor & Tarr, 2008b). Recently, Dupuis-Roy, Fortin, Fiset, and Gosselin (2009) have demonstrated that observers may take a very flexible approach, selecting a variety of cues depending on the information available in a given display and/or the time limits and constraints of a given task.

In related work, using computer-based stimuli in which form information is absent or neutralized, it has been shown motion cues alone can be sufficient for determining the gender of an actor, either from face (e.g., Berry, 1991; Hill & Johnston, 2001) or whole body stimuli (e.g Kozlowski & Cutting, 1977, 1978; Pollick, Kay, Heim, & Stringer, 2005). We were interested in whether motion would also play a role in normal quality video stimuli, when both form and motion cues were available.

Traditionally, facial form and facial motion have been assigned complementary roles within models of face processing (e.g., Bruce & Young, 1986), with the former providing static, invariant cues to identity, gender, race and age and the latter concerned with emotion and communication, via expressions, gestures and visible speech. More recently, it has been shown that both rigid and non-rigid facial motion can serve as reliable cues to individual identity, thus questioning such a strict separation of roles (e.g., Hill & Johnston, 2001; Lander & Bruce, 2000; Thornton & Kourtzi, 2002; O'Toole, Roark & Abdi, 2002; Knappmeyer, Thornton, & Bülthoff, 2003; Pilz, Thornton, & Bülthoff, 2006). Does motion similarly influence gender decisions?

Our prediction, based on previous studies, was that facial motion would provide an additional cue to gender, thus improving performance. However, one issue that is often encountered in studying the impact of facial motion relates to the speed and efficiency with which human observers process static facial form. When form cues are intact, responses are sometimes so rapid that any potential influence of motion is obscured. For this reason, several previous studies have needed to use image degradation, such as blurring, pixilation and contrast reversal, in order to see the effects of motion (e.g., Knight & Johnston, 1997; Lander & Bruce, 2000; Lander, Christie, & Bruce, 1999). This was the initial motivation for introducing picture plane rotation in the current paper. We aimed to make the task a little more difficult to provide motion with an opportunity to exert some influence.

Method

Participants. Twenty-two participants (11 male, 11 female) were recruited from the Swansea University student community. Some were undergraduate students who participated in return for partial course credit, others were graduate students who took part on a voluntary basis. All had normal or corrected to normal vision and were naïve as to the purpose of the experiment.

Task. Observers were asked to make speeded male/female gender categorization responses to faces that appeared, one at a time, in the centre of the computer screen.

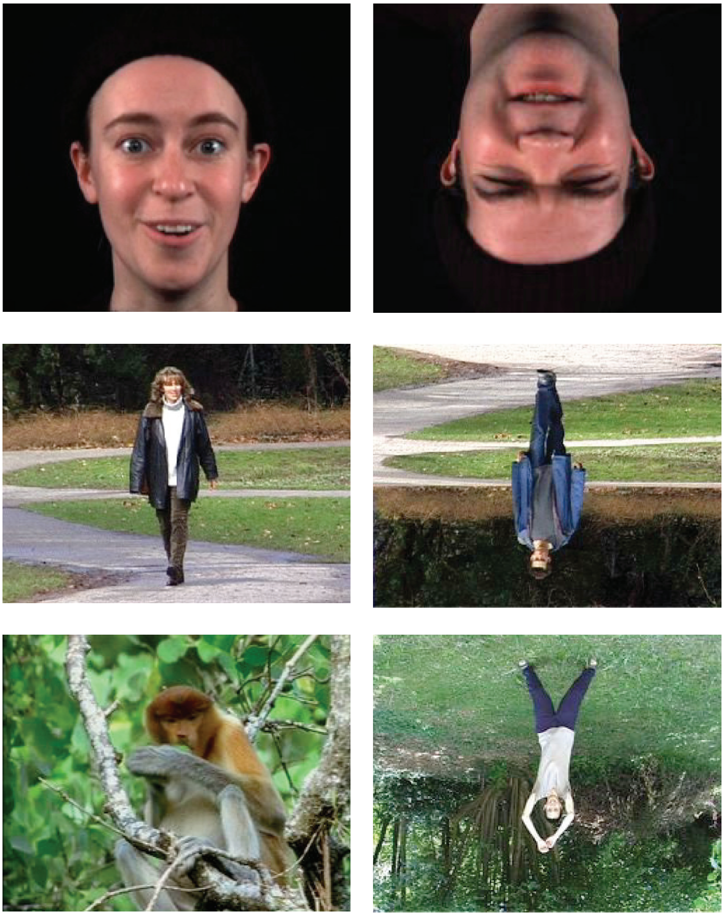

Figure 1. Examples of stimuli used in Experiments 1–3. Note that each type of stimuli was seen in both dynamic and static versions. Upper Row: Male and female faces showing positive (pleasant surprise) or negative (mild disgust) expressions used in Experiments 1 & 2; Middle Row: Male and female full body stimuli used in Experiment 2; Bottom Row: Monkey versus human images used in Experiment 3. See text for further details, image dimensions and durations.

Stimuli. Twenty faces (10 Male, 10 Female) were selected from a video database described in more detail by Pilz,Thornton, & Bülthoff (2006). Figure 1 shows example images. All faces were shown in colour, and orientated in depth directly towards the camera. For each face, two sequences were selected, one involving a positive expression (pleasant surprise), the other a negative expression (mild disgust). Two expressions were used simply to increase the number of target items. Moving sequences lasted for approximately 1 second and disappeared from the screen once completed. Static images were selected by extracting the subjective peak of each expression from the video sequences. The display duration of each static image was also 1 second. An inverted copy of each movie and each static image was created by rotating the stimuli 180° in the picture plane. All images subtended approximately 10 (height) x 9 (width) degrees visual angle.

Design. Each participant completed 160 trials (20 Faces x 2 Orientation x 2 Motion x 2 Expressions) in a separately randomized order.

Equipment. Images were presented using a Macintosh G5 computer using routines from the Psychophysics Toolbox of Matlab (Brainard, 1997; Pelli, 1997). The screen was a 15 inch cinema display (visible area 41cm by 30cm) with a resolution of 1024 x 768 pixels and an effective refresh rate of 75 Hz. Particiants were seated 50 cm from the computer screen.

Results

Both accuracy and reaction time (RT) were analyzed. RT measures were based only on correct responses. Preliminary analysis revealed that neither participant gender nor stimulus gender gave rise to main effects or interactions, so these factors did not form part of the main analysis.

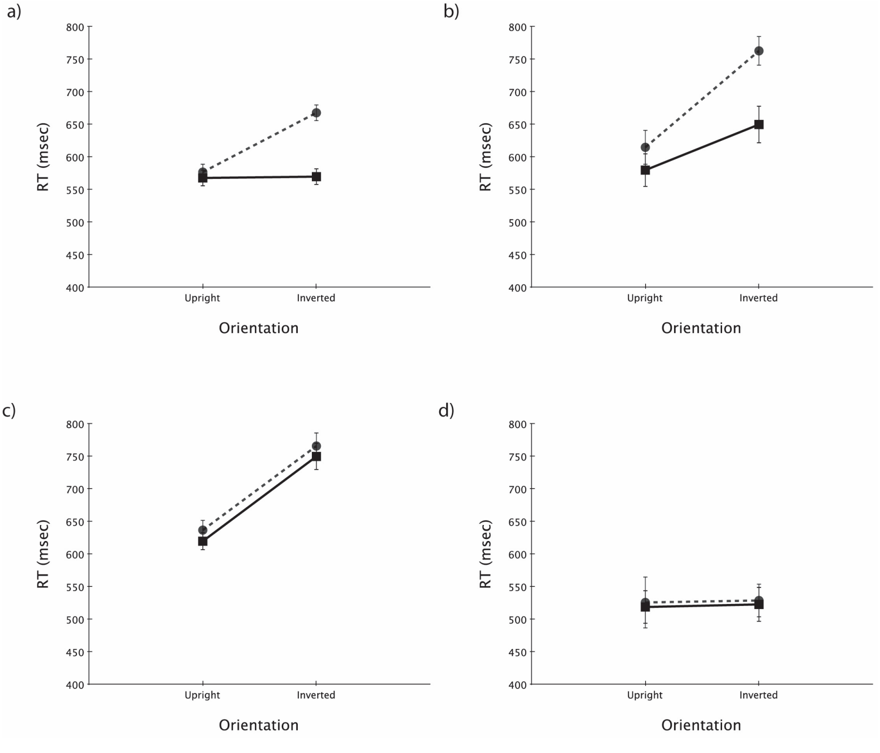

Figure 2. Reaction times, Experiments 1–3. Solid lines are for static presentations, dashed lines for dynamic presentations. Panel a) Gender decisions to human faces in Experiment 1; b) Gender decisions to human faces in Experiment 2; c) Gender decisions to human bodies in Experiment 2; d) Monkey versus human decisions in Experiment 3.

Reaction Time: As expected, observers were able to categorize the sex of the stimuli very rapidly with responses in all conditions remaining below 700 ms. Data were analyzed using a 2 (Expression: Positive, Negative) x 2 (Motion: Moving, Static) x 2 (Orientation: Upright, Inverted) Repeated Measures Analysis of Variance.

There was a main effect of Motion, with Static faces (M=569, SE = 8) giving rise to faster responses than Dynamic faces (M=623, SE = 10), F(1,21)=43, MSE=125, p<.001. There was also a main effect of Orientation, with Upright faces (M=573, SE = 8) giving rise to faster responses than Inverted faces (M=619, SE = 10), F(1,21)=51, MSE=94, p<.001. However, both of these effects must be interpreted in the context of the clear Motion x Orientation interaction, F(1,21)=55, MSE=2, p<.001, shown in Figure 2a. This indicates that both the dynamic disadvantage and the general FIE appear to be driven by a very marked slowing of RTs for inverted moving faces. To confirm the pattern seen in Figure 2a, we computed separate estimates of the FIE for each condition by directly comparing upright and inverted performance. Bonferroni-corrected, paired t-tests indicated highly reliable differences for both positive (M=92, SE=14, t(39)=6.7, p<.001) and negative (M=88, SE=12, t(39)=7.3, p <.001) dynamic conditions, but no differences in the static conditions (both ts <1, ns).

No other main effects or interactions reached significance.

Accuracy: Observers were able to assign the correct gender to the faces with relative ease, with responses remaining above 80% correct in all conditions. The same 2 x 2 x 2 ANOVA used for RTs was used to examine the accuracy data. There was a main effect of Motion, with Static trials (M=90, SE = 0.6) giving rise to fewer errors than Dynamic trials (M=88, SE = 1), F(1,21)=4.5, MSE=1.5, p<.05. There was also a main effect of Orientation, with Upright faces (M=93, SE = 0.7) giving rise to fewer errors than Inverted faces (M=85, SE = 0.8), F(1,21)=50, MS=29, p<.001. In contrast to the RT analysis, there was no Motion x Orientation interaction, and Bonferroni-corrected t-tests confirmed the presence of an FIE in all dynamic and static conditions (all ts> 3, ps <.001). The only other effect to reach significance was an Orientation x Motion x Expression interaction, F(1,21)=10, MSE=2.4, p<.01, which appears to be driven by a slightly larger FIE for moving positive faces than in any of the other condition. As we did not attempt to equate the physical characteristics of the two expressions, this interaction may reflect some subtle difference in speed or quantity of movement.

Table 1. Accuracy and Reaction Time for Experiment 1. Data are shown separately for each expression and as an overall summary. Figures in parentheses are standard error of the mean.

	Smile		Frown		Overall	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
Upright						
Accuracy (%)	92 (1)	94 (1)	95 (1)	91 (2)	93 (1)	93 (1)
RT (ms)	563 (17)	574 (17)	573 (18)	580 (18)	568 (12)	577 (12)
Inverted						
Accuracy (%)	87 (1)	82 (2)	86 (1)	85 (1)	86 (1)	83 (1)
RT (ms)	573 (15)	667 (17)	567 (19)	669 (18)	570 (12)	668 (12)

Discussion

The results of Experiment 1 provide no support for our initial prediction that motion would improve gender decisions. On the contrary, performance was overall a little worse in conditions with dynamic as opposed to static stimuli. This pattern is clearly dominated by the very marked increase in reaction time when moving faces are turned upside-down. Nevertheless, across all conditions, there was no evidence for the sort of dynamic advantage that might be predicted from previous studies of facial identity (e.g., Knappmeyer et al., 2003; Lander & Bruce, 2000; Thornton & Kourtzi, 2002).

Taking the accuracy and RT data together, our findings do in general confirm that turning faces upside-down affects the ability to assign gender, replicating a FIE for this type of task (e.g Bruce et al., 1993; Bruce & Langton, 1994; Bruyer et al., 1993). In static trials, there was little if any RT cost associated with turning faces upside-down. However, a close examination of the means in Table 1, does suggest some modulation in performance in this condition, a pattern that is even more clearly seen in the next experiment.

The most unexpected aspect of these data – and the focus of the rest of this paper – is the apparent amplification of the reaction time FIE for moving stimuli. Finding a performance deficit for motion in a situation where static images are hardly affected is potentially very interesting. Very often when dealing with a dynamic *advantage*, great pains need to be taken to establish that the benefit could not arise simply due to the sum of the additional information content in the component static frames. It could be that there is nothing special about dynamic stimuli, they are just collections of static snapshots. Here, however, we have the opposite situation. Any single static frame could support faster responses than those observed in the dynamic condition. Motion is causing a deficit, but observers do not seem able to ignore it and base their decision on the available static form information.

In the next two Experiments, we first replicate our finding of an amplified dynamic FIE, and then attempt to explore the possible source and specificity of this effect.

EXPERIMENT 2

Although the results of Experiment 1 were framed within the context of the faces, it is possible that observed slowing of dynamic responses has nothing specifically to do with this class of stimuli. Perhaps any form of upside-down dynamic pattern is harder to process than a matched static one? To explore this notion, in Experiment 2, we examined participants gender decisions to two types of stimuli: isolated faces, as in Experiment 1, and full-body walking patterns, as shown in Figure 1, middle row.

We chose walking patterns for several reasons. First, this allowed us to use exactly the same task and experimental design. Second, as with the faces, bodies are highly familiar, salient, dynamic objects. The categorization task should thus be relatively quick and easy, and should not require training. Third, previous research has shown that both static (e.g., Reed, et al., 2003) and dynamic (e.g., Sumi, 1984; Pavlova & Sokolov, 2000) body stimuli are prone to inversion effects.

Method

Participants. Forty participants (20 male, 20 female) were recruited from the same student population as used in Experiment 1. All had normal or corrected to normal vision and were naïve as to the purpose of the experiment. None had participated in the previous experiment.

Task. Observers were asked to make speeded male/female gender categorization responses to images that appeared, one at a time, in the centre of the computer screen. In separate conditions, these images showed either isolated faces or full-body walking figures.

Stimuli. The twenty faces (10 Male, 10 Female) used in this experiment were identical to those from Experiment 1. As expression had not had a major influence on the previous pattern of results, only positive clips were used here. This also allowed us to equate the overall length of the experiment, by reducing the number of face images and replacing them with body images.

The twenty body images (10 Male, 10 Female) were taken from a set of natural walking clips first used by Thornton (2006). Each clip showed an individual walker filmed using a distant camera in a city park and had a maximum duration of 2 seconds. A zoom lens was used to capture several steps from each walker as they made their way along a narrow pathway from a distance of around 60 meters. Walkers were (at least initially) unaware of the camera and their natural gait patterns were unconstrained. The clips also contained a variety of gender-specific clothing (e.g, coat styles) and extraneous items (e.g., handbags, cell phones) and related activity (e.g., swinging a bag, talking on the phone). The video segments used were specifically designed to minimize the impact of the face, (i.e., were from as far away as possible), but nevertheless, pilot testing indicated that gender could unambiguously be assigned with no difficulty. As with the face stimuli, all images subtended approximately 10 (height) x 9 (width) degrees visual angle.

Design. Each participant completed two conditions in separate blocks. One block of trials involved faces, the other bodies. Block order was counterbalanced, with each containing 80 trials (20 Images x 2 Orientation x 2 Motion). Trial order was randomized separately for each participant.

Equipment. This was identical to Experiment 1.

Results

Face-Only Condition

Reaction Time: The general level of response was a little slower than in Experiment 1, although they remained below 800 ms in all conditions. Data were analyzed using a 2 (Motion: Moving, Static) x 2 (Orientation: Upright, Inverted) Repeated Measures Analysis of Variance.

As in Experiment 1, there were main effects of both Motion and Orientation. Static faces (M=615, SE= 19) gave rise to faster responses than Dynamic faces (M=688, SE = 19), F(1,39)=36, MSE=6045, p<.001. Upright faces (M=597, SE = 18) gave rise to faster responses than Inverted faces (M=706, SE = 19), F(1,39)=98, MSE=4876, p<.001. However, both of these effects must again be interpreted in the context of the Motion x Orientation interaction, F(1,39)=10, MSE=5802, p<.01, shown in Figure 2b. This interaction arises as the cost associated with inverted moving images is considerably larger than that associated with static images. A direct comparison of upright and inverted trials confirmed the presence of an FIE for both static, t(39)=4.2, p<.001, and dynamic trials, t(39)=9.3, p<.01. Furthermore, the average size of the FIE was consistently larger for dynamic (M=148, SE=16) than static trials (M=70, SE=17), t(39)=3.2, p<.01.

Accuracy: As in Experiment 1, observers performed very well on the gender categorization task with levels of accuracy remaining above 85% in all conditions. The same 2 x 2 ANOVA used for RTs was applied to the accuracy data. There was a small but reliable main effect of Motion, with Dynamic faces (M=92, SE = .82) giving rise to more accurate responses than Static faces (M=90, SE = .85), F(1,39)=4.4, MSE=36, p<.05. There was again a clear effect of Orientation, with Upright faces (M=95, SE = .64) giving rise to more accurate responses than Inverted faces (M=87, SE = .85), F(1,39)=56, MSE=44, p<.001. There was no Motion x Orientation interaction and the FIE was reliably present for both static (M=9, SE=1.4, t(39)=6.2, p<.0001) and dynamic (M=7, SE=1.4, t(39)=4.7, p<.0001) trials.

Whole Body Condition

Reaction Time: Responses times were comparable, and even a little faster, than in the face only condition, with all responses remaining below 800 ms. Data were analyzed using the same model as above. There was a main effect of

Motion, with Static bodies (M=685, SE = 14) giving rise to faster responses than Dynamic bodies (M=702, SE = 14), F(1,39)=8.7, MSE=1282, p<.01. There was also a clear main effect of Orientation, with Upright bodies (M=629, SE = 10) giving rise to faster responses than Inverted bodies (M=758, SE = 19), F(1,39)=120, MSE=5586, p<.001. As can be seen in Figure 2c, in contrast to faces, body stimuli gave no hint of a Motion x Orientation interaction, and the FIE was reliable and of similar magnitude for both static (M=130, SE = 13, t(39)=10.0, p<.0001) and dynamic (M=129, SE = 13, t(39)=9.8, p<.0001) trials.

Accuracy: Responses to body stimuli were highly accurate, with error rates remaining below 10% in all conditions. The only effect to reach significance was a main effect of Orientation, with Upright bodies (M=97, SE = .5) giving rise to more accurate responses than Inverted bodies (M=94, SE = .85), F(1,39)=15, MSE=21, p<.001. Again, the FIE was reliable and of similar magnitude for both static (M=2.9, SE = 1, t(39)=3.2.0, p<.05) and dynamic (M=2.8, SE = 1, t(39)=2.7, p<.05) trials.

Table 2. Accuracy and Reaction Times for Experiments 2 & 3.
Figures in parentheses are standard error of the mean.

	Face		Body		Monkey	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
Upright						
Accuracy (%)	94 (1)	95 (1)	97 (1)	96 (1)	96 (1)	97 (1)
RT (ms)	580 (25)	615 (26)	620 (13)	637 (15)	519 (25)	526 (39)
Inverted						
Accuracy (%)	85 (1)	88 (1)	94 (1)	94 (1)	96 (2)	97 (1)
RT (ms)	650 (28)	763 (22)	750 (20)	766 (20)	523 (25)	529 (25)

Discussion

The first finding of note from Experiment 2 was that the dynamic amplification of the FIE was again clearly visible. Responses to inverted, dynamic faces were more than 100 ms slower than in any other condition. Unlike Experiment 1, this amplification occurred even in the presence of a small but reliable static FIE.

When observers performed exactly the same task on whole body stimuli, a very different pattern of results emerged. As suggested by previous research (Reed et al., 2003; Sumi, 1984; Pavlova & Sokolov, 2000) there was a body inversion effect for both Static and Dynamic conditions, even for this simple task with intact form cues. Importantly, there was no hint of an interaction.

EXPERIMENT 3

Taken together the results of Experiments 1 and 2 begin to suggest that the dynamic amplification of the inversion effect is not general to all classes of moving stimuli. The whole body stimuli used in Experiment 2 present at least one condition in which there is no apparent difference in the deficit for moving, as compared to static, inverted stimuli.

What remains unclear is whether the dynamic inversion effect is being driven primarily by some aspect of these specfic stimuli – both faces and bodies are known to be affected by inversion – or by the presence of motion. That is, is inverted motion necessarily slower than upright motion? To rule out the possibility of a general deficit associated with turning movies upside-down, we decided to test a situation where the categorization task would not normally be expected give rise to a static inversion effect. We asked observers to make a very simple, superordinate categorization decision to human and animal stimuli. On each trial either a human or a monkey figure was present as a target. Observes simply had to categorize the species.

Our prediction was that such a simple task would not be expected to yield a static inversion effect. Would the addition of motion alter this expected pattern of results?

Method

Participants: Sixteen observers from Swansea University Psychology Department (8 Male, 8 Female) took part in this experiment on a voluntary basis. None of the observers had participated in the previous two experiments and all were naïve as to the purpose of the study. All had normal, or corrected to normal vision.

Task: The task was to categorize each stimulus depending on whether it showed a human or monkey figure.

Stimuli: Ten full-colour human sequences showed a variety of actions, including walking, kicking a ball, jumping and working in a kitchen. Ten, full-colour animal sequences showed various species of monkey doing the things that monkeys like to do. This included, climbing, walking, grooming and jumping. The human stimuli were taken from those used by Thornton (2006), and the monkey clips are described in more detail in Vuong, Hof, Bülthoff, & Thornton (2006). All clips showed figures in fairly complex, natural surroundings and had a maximum duration of 2 seconds. Static clips were frames that were manually selected to show a clear view of the target object. As in the previous experiments, all images subtended approximately 10 (height) x 9 (width) degrees visual angle.

Design: Each participant completed 80 trials (20 Images x 2 Orientation x 2 Motion). Trial order was randomized separately for each participant.

Equipment: This was identical to Experiment 1.

Results

Reaction Time: As expected, observers were able to make the human/monkey classification very rapidly indeed, with responses in all conditions remaining below 550 ms. Data were analyzed using the same 2 (Motion: Moving, Static) x 2 (Orientation: Upright, Inverted) Repeated Measures Analysis of Variance used in Experiment 2. Static stimuli (M=521, SE = 17) did give rise to numerically faster responses than Dynamic stimuli (M=527, SE = 23), and Upright stimuli (M=523, SE = 23) were processed slightly faster than Inverted (M=536, SE = 17), but neither of these main effects approached significance. Similarly, as can be seen from Figure 2d, there is no hint of an interaction and specifically, no modification of responses as a function of motion.

Accuracy: Similarly, error rates remained below 5% in all conditions and were not modified by Motion or Orientation.

Discussion

The purpose of Experiment 3 was to examine the possibility that turning any form of moving stimuli upside-down must necessarily give rise to a deficit, relative to the comparable upright version. In the previous two experiments, the motion condition had always given rise to slower responses, either in the presence (Experiment 2) or absence (Experiment 1) of a similar static inversion effect. The current results provide clear evidence that upside-down motion need not lead to processing deficits.

GENERAL DISCUSSION

In this paper we have presented one situation in which motion has a negative, rather than a positive, impact on face processing. Specifically, in two experiments, the speed of responses in a simple gender categorization task were much slower for moving faces that were turned upside-down, than for any other condition. Compared to an inverted static baseline, responses to inverted moving stimuli were on average 100 ms slower. Compared to upright dynamic faces – to compute the standard face inversion effect (FIE)—there was a clear cost for moving stimuli both in the presence (Exp 2) and absence (Exp 1) of a static face inversion effect. When the same task was performed on whole body stimuli, there was an identical inversion effect for static and dynamic presentations (Exp 2). A simple super-ordinate categorization task showed no inversion effect and no difference between static and dynamic trials (Exp 3).

This dynamic FIE is potentially interesting for several reasons. As already mentioned, facial motion typically improves, or at least does not affect, performance relative to static baseline conditions (see O'Toole, Roark, & Abdi, 2002 for a review). Previous studies of facial motion have shown that dynamic cues survive picture plane inversion, and we could find no previous reports of dynamic inversion causing performance deficits relative to static trials. For example, using animated faces, both Hill & Johnston (2001) and Knappmeyer et al., (2003) found that motion still influenced responses when inverted, albeit at reduced levels. Lander, Christie, & Bruce (1999) continued to find a dynamic advantage when moving faces were compared to multiple static views, even when all faces were presented upside-down. Knight & Johnston (1997) did not find reliable advantages for moving over static stimuli when faces were inverted, although both in normal and photographic negative conditions, the trends were in the direction of a dynamic advantage.

The next point of interest is the fact that form cues remained fully available at all times during the current experiments. Often, in order for the influence of motion to be revealed, such cues need to neutralized in some way, either by holding them constant across all conditions, via the use of computer animation (e.g., Hill & Johnston, 2001; Knappmeyer et al., 2003) or by degrading them (e.g., Knight & Johnston, 1997; Lander & Bruce, 2000; Lander, Christie, & Bruce, 1999). In the current paper, form cues are not only available, but are shown to support performance at levels above those seen with the dynamic stimuli. That is, motion appears to be interfering with performance, but cannot be ignored.

This "mandatory" processing is interesting because while it is well established that both form and motion contribute to the processing of many types of object (e.g, Bernstein & Cooper, 1997; Decety & Grezes, 1999; Grossman & Blake, 2002; Kourtzi, Krekelberg, & Wezel, 2008; Oram & Perrett, 1994; Stone, 1999; Wallis & Bülthoff, 2001), there is still much debate about their precise roles and the level at which such information might be combined (Giese & Poggio, 2003; Haxby, Hoffman, & Gobbini, 2000; Shiffrar, 1994). In specific relation to faces, our data would seem to be most consistent with the model suggested by O'Toole et al., (2003) who proposed amending earlier cognitive (e.g., Bruce & Young, 1986) and neural (e.g., Haxby et al., 2000) models to incorporate greater *interactions* between dorsal, "dynamic" and ventral, "static" aspects of face processing. The current data provide additional evidence against strict independence of form and motion for faces and also argue against the overall dominance of form over motion.

More generally, a number of researchers have suggested that representations of dynamic objects might be fundamentally different from those of static objects (e.g., Freyd, 1987; Kourtzi & Nakayama, 2001; Thornton & Kourtzi, 2002) and there is now considerable evidence to support this claim (e.g., Liu & Cooper, 2003; Newell, Wallraven, & Huber, 2004; Stone, 1999; Vuong & Tarr, 2004; Vuong et al., 2006). Nevertheless, it remains a theoretical possibility that the information content of a moving stimulus is simply the sum of the component static snapshots. That is, there is nothing *qualitatively* different about a moving stimulus, just a difference in *quantity*.

In previous studies of facial motion, this issue has been addressed by including multiple-snapshot conditions, a control that does not lead to the same level of performance as moving faces (e.g., Lander et al., 1999; Pike, Kemp, Towell, & Phillips, 1997; Pilz et al., 2006). Here, we have found that the same transformation (i.e. inversion) has a much larger effect on the moving than on the static faces. This would appear to provide further support for a qualitative account of the difference between static and dynamic face processing. The only way for a quantitative model to account for the current data would be with the additional constraint that processing is not self-terminating. That is, the entire sequence of snapshots must always be processed, and the additional cost of static inversion accumulated, before a response is made. Such a highly inefficient process would also predict much slower responses in the upright dynamic condition, which is not the case. Nevertheless, one way to probe for such processing in a future study would be to vary the length of the dynamic sequence, as the deficit should increase in proportion to sequence length.

In the current work, the question that remains to be answered is *why* motion should lead to a deficit when faces are inverted? Our initial thought was that motion might be interacting with some form of general normalization process, such as mental rotation (Shephard & Metzler, 1971). Several studies have reported an essentially linear increase in the cost of processing unfamiliar faces as the angle or rotation increases in steps between 0 and 180° (e.g., Bruyer, Galvez, & Prairial, 1993; Collishaw & Hole, 2002; Valentine & Bruce, 1988), consistent with such normalization. If such internal transformation required any of the same resources needed to process stimulus motion, then a conflict could arise and produce the increased slowing of reaction times for dynamic over static trials. However, such an explanation would also predict deficits in the dynamic body condition of Experiment 2 or in Experiment 3, where none were observed.

Focusing more specifically on face processing, there appear to be at least three ways in which motion could be interacting with orientation to amplify the FIE. First, motion could alter the availability of feature-based information. Typically, when a face is turned upside-down, features become more important as observers are less able to efficiently extract information about facial configuration. This ability could be affected either because isolated features become harder to locate, track or interpret when upside-down and in motion, or because a dynamic gestalt is simply harder to decompose. Features such as eyebrows (Brown & Perrett, 1993), the gap between eyebrow and the eyelid (Campbell et al., 1999), the jaw (Brown & Perrett, 1993) and the face outline (Yamaguchi et al., 1995) are known to be important for the assignment of gender. If access to these features was made more difficult by the motion-inversion interaction, and if configural cues to gender were already disrupted by inversion (e.g, Bruce et al., 1993; Bruce & Langton, 1994; Bruyer et al.,1993; Stevanage & Osborne, 2006; Rossion, 2002) then an overall drop in performance would be expected.

Secondly, motion may more strongly activate other components of face processing, such as the assignment of expression or identity, even those these are not strictly task relevant. Facial identity processing, for example, appears to affect expression analysis (Schweinberger, Burton, & Kelly, 1999; Schweinberger & Soukup, 1998) speech reading (Schweinberger & Soukup, 1998) and, most relevant in the current context, gender assignment (Stevenage & Osborne, 2006;

Rossion, 2002). If any of these other components are themselves affected by dynamic inversion, then additional costs, relative to static inversion, could occur. Varying the type of motion, for example using rigid rotations of the head or other non-expressive movements of the face (e.g. visible speech), might be one way to further investigate such potential interactions.

Thirdly, motion may be providing a completely independent cue to gender, and that cue itself may be susceptible to an independent inversion effect. As already mentioned in the introduction to Experiment 1, it has been shown that gender can be recovered from both face and body stimuli in the absence of detailed form cues. (e.g., Berry, 1991; Hill & Johnston, 2001; Kozlowski & Cutting, 1977, 1978; Pollick et al., 2005; Troje, 2002). It has also been well demonstrated that such structure-from-motion cues are themselves sensitive to picture plane orientation (Chang & Troje, 2009; Pavlova & Sokolov, 2000; Sumi, 1984; Troje & Westhoff, 2006). If the form cues and motion cues to gender are computed independently, (e.g., Giese & Poggio, 2003; cf. Haxby et al., 2000), and both suffer independent costs of inversion, then this could account for the current amplification of the FIE.

The current data do not let us distinguish between these three possibilities. Clearly, an important next step is to establish whether a dynamic FIE can be observed with other face related tasks and types of motion. We should note that our choice of gender categorization was partly motivated by the fact that motion seemed slightly more orthogonal to this task than in expression categorization – which clearly evolves over time – or identity, where effects of motion are very well established. Race or age decisions may thus provide comparable tasks with which to further probe the specificity of the dynamic FIE.

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