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# Viewpoint and pose in body-form adaptation

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Abstract. Faces and bodies are complex structures, perception of which can play important roles in person identification and inference of emotional state. Face representations have been explored using behavioural adaptation: in particular, studies have shown that face aftereffects show relatively broad tuning for viewpoint, consistent with origin in a high-level structural descriptor far removed from the retinal image. Our goals were to determine first, if body aftereffects also showed a degree of viewpoint invariance, and second if they also showed pose invariance, given that changes in pose create even more dramatic changes in the 2-D retinal image. We used a 3-D model of the human body to generate headless body images, whose parameters could be varied to generate different body forms, viewpoints, and poses. In the first experiment, subjects adapted to varying viewpoints of either slim or heavy bodies in a neutral stance, followed by test stimuli that were all front-facing. In the second experiment, we used the same front-facing bodies in neutral stance as test stimuli, but compared adaptation from bodies in the same neutral stance to adaptation with the same bodies in different poses. We found that body aftereffects were obtained over substantial viewpoint changes, with no significant decline in aftereffect magnitude with increasing viewpoint difference between adapting and test images. Aftereffects also showed transfer across one change in pose but not across another. We conclude that body representations may have more viewpoint invariance than faces, and demonstrate at least some transfer across pose, consistent with a high-level structural description.

Keywords: aftereffect, shape, face, representation

### **1** Introduction

Organic entities, such as animals, bodies, and faces have highly complex structural forms. Nevertheless, our visual system is adept at processing these forms and especially skilled in individuating exemplars of socially important objects such as the human face. Face perception, in particular, has been extensively studied. Recognition of individual faces may depend on highly proficient expert mechanisms (Farah et al 1998; Moscovitch et al 1997), which have behavioural signatures such as the face inversion effect (Rossion 2008; Valentine 1988), in which faces are much harder to recognise when upside down, and the face composite effect (Young et al 1987), in which perception of one half of the face is influenced by perception of the other half.

Given the physical linkage and similarities in social significance and encounters between faces and bodies, parallels and contrasts between the processing of these two stimulus types have been made (Minnebusch and Daum 2009; Peelen and Downing 2007). Neuroimaging studies have shown that face processing involves a core occipitotemporal face network with enhanced activation by faces compared to other object classes, including the occipital face area, the fusiform face area, and the superior temporal sulcus (Fox et al 2009; Gobbini and Haxby 2007; Haxby et al 2000). Recent work in humans has also revealed parallel circuitry

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for the visual processing of bodies (Minnebusch and Daum 2009; Peelen and Downing 2007), with the extrastriate body area, the fusiform body area, and a body-responsive region in the superior temporal sulcus all located in proximity to their face counterparts. The fusiform body area and the extrastriate body area show heightened responses to body images, body silhouettes, and stick figures representing bodies (Downing et al 2001; Peelen and Downing 2005), and regions with analogous body selectivity have been shown in the monkey (Pinsk et al 2009). Also, as with faces, body perception generates predominantly right-sided activity in right-handed subjects (Willems et al 2010).

The functional nature of body representations in the perceptual system and their similarity to face representations are less clear, though. There have been demonstrations of a behavioural body-inversion effect (Reed et al 2003, 2006), though this has been investigated mainly for body pose rather than body form; furthermore, there are arguments that this body-inversion effect derives mainly from the head region (Yovel et al 2010) and reflects activity in face-processing regions (Brandman and Yovel 2010). One study replicated the composite effect for upright but not inverted faces but did not find a similar phenomenon for upright or inverted body forms (Soria Bauser et al 2011). Hence, whether body perception uses expert configural or 'holistic' processes similar to those used by face perception is not settled.

Adaptation offers a powerful means to explore the nature of stimulus representations, and has been applied extensively to the study of face perception (Leopold et al 2001; Webster and MacLeod 2011). By changing properties between the adapting and test stimuli it is possible to determine the types of invariance (or malleability) in the neural representations of stimuli. Thus, for example, face identity aftereffects transfer completely across changes in expression between adapting and test stimuli (Fox et al 2008), indicating that identity representations are highly invariant for expression content. On the other hand, face expression aftereffects transfer only partially across changes in identity (Fox and Barton 2007), indicating a more limited invariance for expression representations. Manipulations of the spatial relations of facial features in adapting test stimuli have shown that face identity aftereffects require a correct first-order arrangement of features, indicating that face representations are not simply loose collections of features but integrated structural units (Pichler et al 2011).

One property typical of high-level stimulus representations is viewpoint invariance. Changes in viewpoint significantly alter the retinal or 2-D image of complex 3-D structures like faces and bodies. Despite this, neurophysiologic studies of monkey inferotemporal cortex show that a few neurons have viewpoint-invariant responses, while many of the rest show a viewpoint-dependence that has relatively broad tuning for viewpoint (Booth and Rolls 1998; Logothetis et al 1995). Similarly, human fMRI adaptation studies have shown both viewpoint-dependent and viewpoint-invariant responses in lateral occipital cortex and fusiform gyri (Kourtzi et al 2003; Vuilleumier et al 2002).

Behavioural adaptation studies have been used to show that face aftereffects are partially viewpoint-invariant (Benton et al 2006; Jeffery et al 2006, 2007; Jiang et al 2006), consistent with their origin in high-level representations, rather than in low-level properties like contrast and orientation (Butler et al 2008). Adaptation studies of the perception of body form are few so far (Glauert et al 2009; Winkler and Rhodes 2005) and have not yet examined modulation by viewpoint. One study of adaptation for body orientation has suggested different channels for right and left facing poses, as well as evidence for a multi-channel encoding system (Lawson et al 2009); however, studies of orientation do not directly address the nature of *body form* representations. Beyond viewpoint, bodies also offer one considerable advantage for exploring high-level representations over faces: the arrangement of the limbs and torso can be radically rearranged by changes in pose, altering the retinal image of bodies to a degree not possible for faces, even with changes in expression. This permits a more extensive exploration of the malleability of object representations.

In this report, our goal was to use adaptation of body form perception to examine the nature of the neural representations of body structure in our visual system. In the first experiment, we examined the hypothesis that body aftereffects would show a similar degree of viewpoint invariance as faces. If so, this would suggest that the neural representations for these two types of 3-D objects share a similar tuning for viewpoint, and that there may be a general strategy for extrapolation of form across viewpoint, an important function in a 3-D world. In the second experiment, we examined whether body form adaptation transferred across difference poses, in which the positions of the limbs and torso with relation to each other were significantly altered. This can be viewed as a test of the tolerance of the neural representations of body form to radical deformations in the retinal image. Again, given the fact that we live in a world of dynamic objects with moveable parts, object constancy may indeed require a degree of invariance for such deformations.

### 2 Experiment 1: Viewpoint invariance

#### 2.1 *Methods*

2.1.1 *Participants*. Sixteen healthy volunteers naive to the purpose of the experiment participated (nine male, seven female), with mean age of 30.1 years (25–56 years range), all with normal or corrected vision. The Institutional Review Boards of the University of British Columbia and Vancouver Hospital approved the protocol of both experiments. All subjects gave informed consent in accordance with the principles of the Declaration of Helsinki.

2.1.2 *Stimuli*. Male and female body images were generated from a realistic 3-D model of the human body created from laser range scans of over 2000 people (Tsoli and Black 2011) (see http://www.bmivisualizer.com/ for an example). Statistical machine learning methods were used to separate body shape variations due to identity from those due to pose. By varying the parameters of the model we generated realistic body shapes in front facing and rotated views as well as in different poses. We used images of four bodies in a neutral stance, with arms away from the side: slim male, heavy male, slim female, and heavy female. These were viewed from a front-facing position (0°) as well as views rotated by 30° increments, giving a total of 8 different images of an upright headless body. Images were in colour and presented on a white background. These images were used as adapting stimuli and in the choice display screens in the experiment.

To create test stimuli, we used the front-facing views  $(0^{\circ})$  of these bodies, and using FantaMorph5 software (www.fantamorph.com) morphed from the slim to the heavy versions, for both the male and female bodies, in 3% steps. For ambiguous test stimuli we selected the 11 morphed images from the middle of the morphing range from 35% slim/65% heavy to 65% slim/35% heavy.

2.1.3 *Procedure*. The protocol was designed and conducted with SuperLab 4.0 (www.cedrus. com) and images were displayed on an HP 6730B notebook 15.4-WXGA display.

A trial consisted of a sequence of events (figure 1). First, an adapting image was presented on the screen for 5 s. This could be either a heavy or a slim body, male or female, and in one of 5 possible viewpoints (0°, 30°, 60°, 90°, or 180°, see figure 2). Half of the subjects performed an experimental version where all viewpoints were rotated clockwise, and half a version with all viewpoints rotated counterclockwise. After the adapting image, there was a noise mask for 50 ms, and then a blank screen for 150 ms. 1 of the 11 ambiguous test images with the same gender as the adapting image then appeared for 300 ms, followed by a choice display showing both the heavy and the slim body for that gender, which remained visible until the participant responded. The task was to state whether the test image looked more like the slim or the heavy body, by pressing either "A" for the body on the right (which was either the heavy female or slim male) or "L" for the body on the left (which was either the slim female or heavy male).



**Figure 1.** Method. Adapting stimuli were slim or heavy bodies viewed for 5 s. In experiment 1 they were posed in neutral stances seen front-facing or in various viewpoint rotations—in this example, 60° clockwise. In experiment 2 they were posed in front-facing neutral stance or different poses, as illustrated in figure 3. Adapting stimuli were followed by a mask, a blank screen, and then the test image was shown for 300 ms. Test images were ambiguous stimuli created by morphing between the slim and the heavy body, and always seen in front-facing neutral stance. After the test image, a choice display appeared, showing the slim and the heavy bodies, and the subject responded which of the two the test image most resembled.

To minimise the contribution of adaptation for low-level retinotopic features, subjects were allowed to move their eyes, and the sizes of the images differed, with the test stimuli 10% smaller than the adapting images, and the choice display images the same size as the adapting stimuli, but displaced laterally. Adapting images were 15 cm in height, which at a viewing distance of 50 cm is equivalent to 16.9 deg.

Each of the 20 adapting stimuli was paired once with each of the 11 test stimuli, to give a block of 220 trials total, with trial order randomised. The experiment took approximately 30 min to complete.

To familiarise subjects with the protocol, the experiment was preceded by a training session in which subjects were given 10 adaptation trials of an identical nature apart from using viewpoints rotated in the direction not used in the experiment for that subject. No feedback was given.

2.1.4 *Analysis.* For each subject we calculated the aftereffect magnitude over all morph test stimuli, as the difference in the frequency of "slim" responses between adapting to a



**Figure 2.** Results, experiment 1. Main graph shows the mean aftereffect magnitude, calculated as the frequency of 'slim' responses after adapting to the heavy body, minus the frequency of 'slim' responses after adapting to the slim body, averaged over all morphed stimuli, for each subject, and shown for each viewpoint condition, as illustrated by the body images. Bars indicate one standard error, asterisks indicate significant aftereffects, and pound sign (#) indicates trend after correction for multiple comparisons. Insets above the main graph show the group psychometric curves for each viewpoint condition, plotting the frequency of 'slim' responses' as a function of the percent content of the heavy image in the morphed stimulus, after adapting to the heavy body (black symbols and lines), and after adapting to the slim body (grey symbols and lines). Numbers in italics are the regression coefficients for the fit of each psychometric curve.

heavy body and adapting to a slim body. First we used one-way *t*-tests with Bonferroni correction for multiple comparisons, adjusted for across-item correlation (Sankoh et al 1997) to determine whether the aftereffect magnitude was significantly different from zero for each of the 5 viewpoint conditions (adjusted  $\alpha = 0.019$ ). Next, to examine the effect of viewpoint, we used a repeated-measures ANOVA with main factor of viewpoint rotation (0°, 30°, 60°, 90°, 180°) with subjects as a random effect, followed by the Tukey's honestly significant different (HSD) test to examine for significant contrasts between conditions. In this and the following experiment we collapsed the results across the gender of the stimuli, as an initial ANOVA that included this as a factor did not show any significant main effect or interaction involving gender.

To test specifically for a decline in aftereffect magnitude with increasing difference in viewpoint, we also calculated for each subject the slope of the regression line for aftereffect magnitude as a function of viewpoint, and used a *t*-test to examine whether this slope differed significantly from zero.

For illustrative purposes, we averaged responses across all subjects for each morph level, to allow us to plot the psychometric curves for response as a function of stimulus content. We fitted curves to these group mean data, using least-squares linear regression of normalised (*z*-transformed) frequency-of-response data (Simpson 1995): the goodness of fit of these lines we report as regression coefficients in the figures.

# 2.2 Results

First, without a change in viewpoint, we confirm a significant body-form aftereffect (mean 11.4%, SD 18.5%,  $t_{15} = 2.45$ , p < 0.013) (figure 2). Significant aftereffects were also found transferring from the 60° (mean 13.3%, SD 19.3%,  $t_{15} = 2.75$ , p < 0.007) and 90° viewpoints (mean 10.8%, SD 13.8%,  $t_{15} = 3.14$ , p < 0.004), with a trend from the 180° viewpoint (mean 7.7%, SD 14.5%,  $t_{15} = 2.11$ , p < 0.026). Transfer from the 30° viewpoint just failed to reach the trend level (mean 8.2, SD 19.6,  $t_{15} = 1.66$ , p = 0.059). The ANOVA showed no main effect of viewpoint ( $F_{4,12} = 0.49$ , p = 0.73). Tukey's HSD test did not show a difference between any pair of viewpoints, at an  $\alpha$  level of 0.05. In particular, there was no significant difference between the 0° front-facing viewpoint and any other viewpoint. Consistent with this, the slope analysis did not find a significant decline in aftereffect magnitude with increasing difference in viewpoint between adapting and test stimuli (b = -0.016, SD 0.086,  $t_{15} = 0.73$ , p = 0.48).

# 3 Experiment 2: Pose invariance

## 3.1 Methods

3.1.1 *Participants*. Sixteen different subjects participated in this study (four male, twelve female) with a mean age of 32.3 years (23–55 years range).

3.1.2 *Stimuli*. We used the same 4 bodies as in experiment 1: slim male, heavy male, slim female, and heavy female. However, in addition to the front-facing neutral stance, we also obtained images of these bodies in a number of random poses. Two were chosen with the properties that they represented a significant change from the neutral stance and yet preserved the view of much of the limbs and torso. These images were used as adapting stimuli and in the choice display screens in the experiment. As test stimuli we used the same morphed images used in experiment 1, in the front-facing neutral stance.

3.1.3 *Procedure*. Trials consisted of a sequence of events similar to experiment 1. Adapting images could be either a heavy or a slim body, male or female, but in this experiment in one of 3 poses (front-facing neutral or  $0^{\circ}$  stance, pose 1, or pose 2, see figure 3). The test stimulus was again one of the 11 ambiguous morphed body stimuli, always in the front-facing neutral stance, with the same gender as the adapting image. The choice display showed both the heavy and the slim body in front-facing neutral stance for that gender. The task again was to state whether the test image looked more like the slim or the heavy body. As in experiment 1, adapting, test, and choice images differed in size.

Each of the 12 adapting stimuli was paired once with each of the 11 test stimuli, to give a block of 132 trials total, with trial order randomised. The experiment took approximately 20 min to complete.

To familiarise subjects with the protocol, the experiment was preceded by a training session in which subjects were given 10 adaptation trials of an identical nature, apart from using as adapting stimuli bodies with poses different from those shown in the experiment.



**Figure 3.** Results, experiment 2. Main graph shows the mean aftereffect magnitude, calculated as the frequency of 'slim' responses after adapting to the heavy body, minus the frequency of 'slim' responses after adapting to the slim body, averaged over all morphed stimuli, for each subject, and shown for each pose condition, as illustrated by the body images. Bars indicate one standard error, and asterisks indicate significant aftereffects. Insets show the group psychometric curves for each pose condition, plotting the frequency of 'slim' responses' as a function of the percent content of the heavy image in the morphed stimulus, as in figure 2. Numbers in italics are the regression coefficients for the fit of each psychometric curve.

3.1.4 Analysis. After calculating each subject's aftereffect magnitude, we again used oneway *t*-tests with Bonferroni correction for multiple comparisons, adjusted for across-item correlation, to determine whether the aftereffect magnitude was significantly different from zero for each of the 3 pose conditions (adjusted  $\alpha = 0.025$ ). To examine the effect of pose, we used a repeated-measures ANOVA with main factor of pose (front-facing—0°, pose 1, pose 2) with subjects as a random effect, followed by the Tukey's HSD test to examine for significant contrasts between conditions.

As in experiment 1, for illustrative purposes, we plotted the psychometric curves for the group mean data, for response as a function of stimulus content. We fitted curves using least-squares linear regression of normalised (*z*-transformed) frequency-of-response data (Simpson 1995): the goodness of fit we report as regression coefficients in the figures.

### 3.2 Results

We replicated the finding of a significant body-form aftereffect for the same front-facing neutral pose (14.2%, SD 17.8%,  $t_{15} = 3.18$ , p < 0.004). There was a significant aftereffect transfer from pose 1 (7.9%, SD 11.3%,  $t_{15} = 2.80$ , p < 0.007), but not from pose 2 (-2.3%, SD 14.5%,  $t_{15} = 0.66$ , p = 0.27). The ANOVA showed a main effect of adapting pose ( $F_{2,14} = 8.01$ , p < 0.002): Tukey's HSD test showed that aftereffects after adapting to pose 2 were significantly less than those after adapting to the front-facing neutral pose ( $t_{15} = 3.97$ , p < 0.0004, Cohen's d = 1.02), but no other contrasts were significant at an  $\alpha$  level of 0.05.

## 4 Discussion

These results first confirm that aftereffects for body form exist. They complement prior work showing that adapting to thin or overweight bodies results in a shift of what is perceived as normal or attractive towards the adapting image (Glauert et al 2009; Winkler and Rhodes 2005). In our study, a similar shift of the perceived midpoint between the slim and the heavy images towards the adapting body image would increase the frequency of responses that any given morphed test image looked more like the unadapted body. Second, they suggest that there is very little if any decline in aftereffect magnitude with changes in viewpoint, contrasting with the case of face aftereffects, which decline with viewpoint changes of 30° to 90° (Benton et al 2006; Jeffery et al 2006; Jiang et al 2006). Third, body-form aftereffects can transfer between some poses, but not all. Hence there is a degree of tolerance or invariance for transformations of the body form in its neural representation, but with some limits.

Viewpoint effects have been studied extensively in face adaptation. Careful distinction must be drawn between viewpoint aftereffects and adaptation transfer across viewpoints. In viewpoint aftereffects, subjects are more likely to perceive the view of the face as shifted in the opposite direction to the viewpoint of the adapting face, an aftereffect that transfers partially from one identity to another (Fang et al 2007). An analogous aftereffect has been studied for facing direction of light-point walkers, which give the impression of a moving body (Theusner et al 2011). In adaptation transfer across viewpoints, as studied in our first experiment, adaptation to some facial property such as identity, age, gender, or expression is measured, and its ability to transfer from one viewpoint to another is assessed (Benton et al 2006; Jeffery et al 2006; Jiang et al 2006).

A number of studies have shown that adaptation to facial identity does transfer across viewpoint (Jiang et al 2006), but only partially. While all agree that aftereffect magnitude declines when viewpoint differs between adapting and test stimuli, the magnitude of this reduction and the rate of its decline with the degree of change in viewpoint vary between studies. One reported a reduction in aftereffect by about a third with a viewpoint change of  $30^{\circ}$  (Jiang et al 2006). A second found a reduction of about half with a viewpoint difference of 45°, with no further increase at a difference of 90° (Jeffery et al 2006). A third found an approximately linear decline in aftereffect magnitude as the viewpoint difference increased, eventually culminating in about a third reduction with their maximum viewpoint difference of 90° (Benton et al 2006). Somewhat similar to this last finding, a study of opposing contingent aftereffects—in which aftereffects induced by viewing an inflated face are countered by simultaneous viewing of a second contracted face-reported a gradual decline in this cancellation effect as the difference in viewpoints between the two faces increased up to 60° (Jeffery et al 2007). Paralleling these behavioural studies, an fMRI adaptation study showed that identity-related adaptation effects for faces in the fusiform face area were reduced when viewpoint changed by 45° to 90° (Andrews and Ewbank 2004). An MEG study produced an even more drastic finding of loss of adaptation of the face-selective component of the M170 potential with viewpoint changes of as little as 2° to 8° (Ewbank et al 2008), which was interpreted as evidence of origin of the face-selective M170 in very early stages of face processing.

In contrast to these face-adaptation studies, the body-form aftereffects we found with 60° or 90° differences in viewpoint between adapting and test stimuli were just as large as the same-view aftereffects. Why do body form aftereffects in our experiment remain so robust across all changes in viewpoint, while face identity aftereffects decline? It may be that this reflects the relatively cylindrical structural organisation of the human body. Changes in body mass index between images, as in our stimuli, may be evident to a similar extent across most rotations of viewpoint. Perceptibility of changes in other aspects, such as the lengths and aspect ratios of the limbs or torso, would also be expected to remain relatively unaffected by changing the view of a body in a front-facing neutral pose, as long as the altered structures remain visible. While the head is a spheroid, the face itself is a complex convex hemisphere, concentrated anisotropically on the front of the head, and whose identifying irregularities differ widely in their 2-D projection after viewpoint rotation: hence, view change may generate a more radical transformation for faces than for bodies.

For this reason it is of interest to explore the effects of pose on body-form aftereffects. The structural relations between the 4 limbs and torso are highly fluid in real life, and a significant degree of invariance would be required to maintain stable recognition of body identity. For faces, the closest analogous change in structure might be the moment-to-moment variation in the position and shape of mobile facial features created by expression or speech. Studies have shown that face identity aftereffects show complete transfer over changes in expression (Fox et al 2008). However, facial mobility is limited to motion of the jaw and movement of soft tissue induced by changes in muscle tension, as most of the underlying skeletal structure of the skull is rigid. Hence expression-induced changes are relatively minor transformations compared to the changes in body images induced by alterations in pose, given the numerous joints in the body. The current study shows that body aftereffects can indeed transfer across widely different poses, though transfer may not occur for all pose transformations. Nevertheless, the fact that transfer occurs between at least some poses indicates a substantial tolerance for pose variations in the neural representations of bodies that are being adapted.

There are limitations to our conclusions that require study in further experiments. First, while we found robust transfer of aftereffects across viewpoint for the neutral stance, it is not known whether this would be true for other body poses. In particular, if the cylindrical organisation of the human body is key to the viewpoint invariance of our results, poses with the torso and limbs placed in some orientation other than parallel to the axis of viewpoint rotation may result in foreshortening distortions (eg see the left thigh in pose 2, figure 3) that limit transferability of adaption across viewpoint. Second, the reasons why transfer occurs between some poses but not others in our study need to be clarified. One might speculate that reduced adaptation from our pose 2 is related to the fact that this pose is more squat, with greater changes in joint angle in the legs, and possibly the foreshortening that limits the view of one body element, namely the left thigh. However, this requires quantitative evaluation in future experiments, with exploration of the metrics of pose change to determine the broadness of pose-tuning demonstrated by body-form aftereffects.

Our results show a significant malleability in the high-level representations of body form, which allows transfer of adaptation across substantial changes in viewpoint and pose. These types of studies may be of interest to establish the flexibility of object representations in conditions such as general visual agnosia. It may also be that such representations are affected in prosopagnosic subjects, given the proximity of body-responsive to face-responsive areas on functional imaging. Furthermore, studies of body form adaptation may reveal distortions in perception of body image in conditions such as body dysmorphia.

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