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Visual adaptation after effects for muscularity are body-part specific

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Abstract

Visual adaptation to extreme body types is known to produce contrastive adaptation aftereffects on the subsequent perception of human bodies. This approach has been exploited to probe the perceptual mechanisms underlying body perception by measuring the extent to which aftereffects occur when the adapting and test stimuli differ in specific characteristics (*cross adaptation*). The present study used this approach to investigate the body-part specificity of adaptation to body muscularity. Participants made judgments of the muscularity of torsos and arms both before and after adaptation to muscular torsos (Experiment 1) or muscular arms (Experiment 2). Across experiments, we report a double dissociation in the effects of adaptation. In Experiment 1, adaptation to muscular torsos produced aftereffects for torso judgments, but not arm judgments. In Experiment 2, adaptation to muscular arms produced aftereffects for arm judgments, but not torso judgments. These results demonstrate body-part specificity of the visual mechanisms underlying perception of body muscularity.

Keywords

Adaptation/constancy, body perception, muscularity, aftereffects

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Introduction

Our body is intimately familiar to us and forms the core of our personal identity. Despite this, there is increasing evidence that distortions and misperceptions of the body are a ubiquitous part of healthy mental life (Longo, 2022). Systematic distortions of body perception have been found in many domains, including tactile distance perception (e.g., Cholewiak, 1999; Fiori & Longo, 2018; Longo & Haggard, 2011; Weber, 1834), proprioception (e.g., Cocchini et al., 2018; Coelho & Gonzalez, 2019; Ganea & Longo, 2017; Longo & Haggard, 2010), conceptual knowledge of body layout (e.g., Ambroziak et al., 2018; Longo, 2015; Myga et al., 2021), perceived

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body part weight (e.g., Cadete et al., 2025a, 2025b; Ferrè et al., 2023), and experienced body size and shape (e.g., Dolan et al., 1987; Dolce et al., 1987; Longo & Haggard, 2012; Tavacioglu et al., 2019; Thompson & Thompson, 1986). While such distortions appear to be a normal part of healthy mental life, there is also evidence that the magnitude of misperception is linked to unhealthy attitudes towards the body (Maister et al., 2021; Moon et al., 2020). Indeed, excessive misperception of the body is a core feature of serious mental illnesses, including eating disorders (e.g., Dakanalis et al., 2016; Garfinkel et al., 1979; Slade & Russell, 1973; Thompson et al., 1986) and muscle dysmorphia (e.g., Devrim et al., 2018; Hildebrandt et al., 2004; Pope et al., 2000).

Adaptation aftereffects refer to systematic changes in perception caused by extended exposure to stimuli (P. Thompson & Burr, 2009). In a typical experiment measuring adaptation aftereffects the threshold of some perceptual judgment is measured both before and after adaptation to a stimulus. Aftereffects manifest as a systematic bias in perceptual thresholds following adaptation. Classically, aftereffects have been described for low-level stimulus features such as visual motion (Anstis et al., 1998; Barlow & Hill, 1963), colour (McCollough, 1965; Vul & MacLeod, 2006), size (Blakemore & Campbell, 1969; Blakemore & Sutton, 1969), orientation (Clifford, 2014; Gibson & Radner, 1937), and curvature (Coltheart, 1971; Gibson, 1933). More recently, aftereffects have also been described for more ‘high-level’ stimuli, such as for faces (e.g., Leopold et al., 2001; Rhodes et al., 2003; Webster et al., 2004) and for human bodies (Challinor et al., 2017). Studies have shown that several features of bodies can be adapted, including orientation (Lawson et al., 2009), gender (Palumbo et al., 2013), adiposity (Ambroziak et al., 2019; Hummel et al., 2012; Sekunova et al., 2013; Stephen et al., 2018; Winkler & Rhodes, 2005), and muscularity (Brooks et al., 2020a; Sturman et al., 2017). Such effects have attracted substantial interest given the possibility that short-term aftereffects may serve as an experimental model to study the well-established role of mass media depiction of bodies on body image (Brooks et al., 2020b).

Many studies have explored high-level aftereffects by investigating how they generalise when the adapting and test stimuli differ in specific characteristics, an approach known as *cross-adaptation*. By determining how aftereffects generalise across different categories, researchers can determine how broadly or narrowly-tuned the underlying perceptual representations are. In the context of body perception, cross-adaptation has been used to show at least partial generalisation of aftereffects across bodies differing in identity (Brooks et al., 2016; Hummel et al., 2012), orientation (Brooks et al., 2018), race (Gould-Fensom et al., 2019), and gender (Brooks et al., 2019, 2020a). A similar logic has been applied to investigate whether such perceptual representations are body-part specific or generalise across the entire body. For example, several studies have shown that aftereffects transfer at least partially between bodies and faces (Ambroziak et al., in press; Cooney et al., 2015; Ghuman et al., 2010; Kessler et al., 2013; Palumbo et al., 2015), indicating coherent representations of whole-persons. Similarly, a recent study showed that adaptation to extreme hand shapes produced aftereffects on judgments of whole body shape (Ambroziak et al., 2023).

Two recent studies have investigated the body-part specificity of adaptation aftereffects (Bratch et al., 2021; Ip et al., 2024). Bratch and colleagues (2021) measured aftereffects on judgments of forearm length. They found clear aftereffects after participants were adapted to extreme arms, but critically not when the adapting stimuli were legs or non-body objects. Ip and colleagues (2024) investigated aftereffects for perceived body muscularity. Their stimuli showed either the top half of the body (above the waist), or the lower half (below the waist). Clear aftereffects were found when the adapting and test stimuli matched (i.e., both upper half or both lower half), but only small and inconsistent aftereffects were observed when they mismatched. Ip and colleagues interpret their results as evidence for distinct perceptual representations of the upper and lower body.

These two studies provide clear evidence for some level of body-part specificity for adaptation aftereffects. The exact nature of this specificity, however, remains unclear. Both studies compared stimuli from the upper and lower bodies, but it is unclear whether the upper/lower distinction itself matters, or whether it simply matters that different body parts are shown. In the present study, we addressed this issue by investigating cross-adaptation for muscularity aftereffects for two body parts which are both on the upper half of the body: the arms and the torso. If the perceptual representations underlying body adaptation are selective for the upper vs. lower body, then cross-adaptation should be found, since all stimuli are from the upper half of the body. In contrast, if these representations reflect distinct body parts regardless of body half, then greater aftereffects should be found when adapting and test stimuli are congruent than incongruent. We measured judgments of muscularity of torsos and arms before and after adaptation to muscular torsos (Experiment 1) or muscular arms (Experiment 2). To anticipate our results, in both experiments we find clear body-part specific aftereffects.

Experiment 1

The first experiment investigated aftereffects on the perceived normality of arms and torsos varying in muscularity before and after adaptation to a highly muscular torso.

Method

Participants. Thirty men between 18 and 40 years of age (*M*: 24.9, *SD*: 5.8) were recruited from the local community and social network of the researchers. Participants gave written informed consent and procedures approved by the School of Psychological Sciences Research Ethics Committee at Birkbeck.

In our recent study showing transfer of adaptation from hands to full bodies (Ambroziak et al., 2023), the effect size for the *t*-test comparing baseline and adaptation judgments for the large adaptor was $d_z = 0.67$. We conducted a power analysis using G*Power 3.1 software (Faul et al., 2007) using this effect size, alpha of .05, and power of .90, which indicated that 26 participants were needed. Thus, our sample size is appropriately powered to detect a comparable transfer of adaptation between torsos and arms.

Stimuli. Stimuli were created using the Genesis 8 male model in Daz 3D software (Daz Productions, Salt Lake City, UT). Muscularity was manipulated by changing the pre-set, whole-body slides for *Muscularity* and *Emaciation*. These parameters range from 0 to 100 and were manipulated simultaneously subject to the constraint that their sum equal 100. Thus, as muscularity increased, emaciation decreased, and vice versa. Following Ip and colleagues (2024), we created 25 equally-spaced levels of muscularity for both torsos and arms, resulting in 50 stimuli in total. For example, a muscularity score of 1 was assigned to a model with 100% emaciation and 0% muscularity, while a score of 25 was assigned to a model with 0% emaciation and 100% muscularity. Examples of these stimuli are shown in Figure 1A.

In order to ensure that adaptation aftereffects generalised across personal identities, we varied the skin tone of each stimulus so that they appeared to be different people. Distinct skin tones were created within Daz Studio and were randomly assigned to the 50 stimuli. In addition, we introduced variation between stimuli in body shape. For torso stimuli, we randomly varied the *torso shape* and *chest shape* parameters, while for arm stimuli were randomly varied the *limb length* and *arm scale* parameters. This resulted in a diverse array of body shapes and skin tones. These procedures are similar to those used by Ip and colleagues (2024).

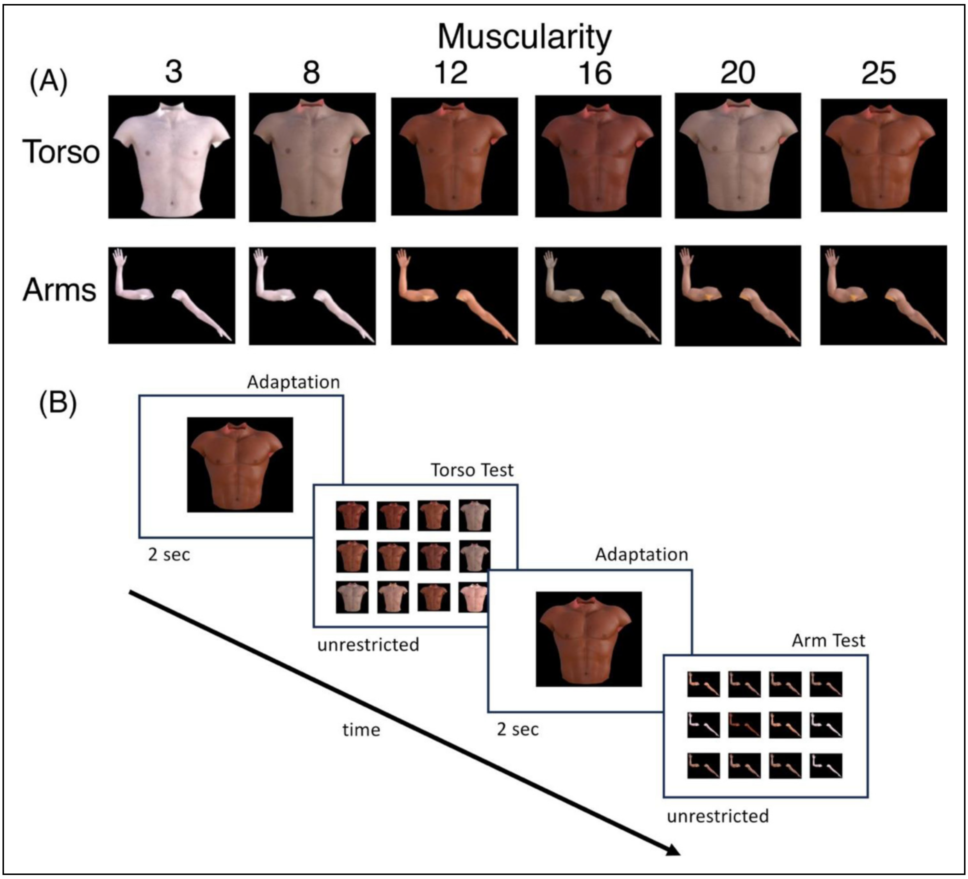

Figure 1. Stimuli and procedure. (A) Examples of torso and arm stimuli. Muscularity was manipulated on a continuum from 1 to 25. Skin tones were randomly assigned to stimuli so that they appeared to be different identities. (B) Time-line of two trials during the adaptation phase.

Procedure. The study was implemented using the online Gorilla platform (Anwyl-Irvine et al., 2020). On each experimental trial, participants were shown a 3 × 4 grid of stimuli, with 12 randomly selected levels of muscularity (see Figure 1B). The position of the 12 stimuli in the grid was also random. The width of the 12 images presented was held constant as 1/6th of the width of the screen. On some trials, the stimuli were torsos and in other trials they were arms. The participant's task was to click on the image which appeared to them to represent the most normal muscularity of a male in the UK.

To familiarise participants with the task and minimise learning effects, four practice trials were presented at the start of the task, two torso trials and two arm trials. The main experiment was divided into two parts. In a pre-adaptation *baseline* block, the participant completed 24 trials, 12 each involving torso and arm stimuli. Torso and arm trials alternated.

The core manipulation took place during the *adaptation* block, which started by showing a series of 4 highly muscular (i.e., muscularity of 25) chest models for 2 s each, with the entire cycle repeating 16 times. This resulted in an adaptation period of 128 s. This is identical to the initial adaptation period used by Ip and colleagues (2024) and similar to that used in previous studies of body

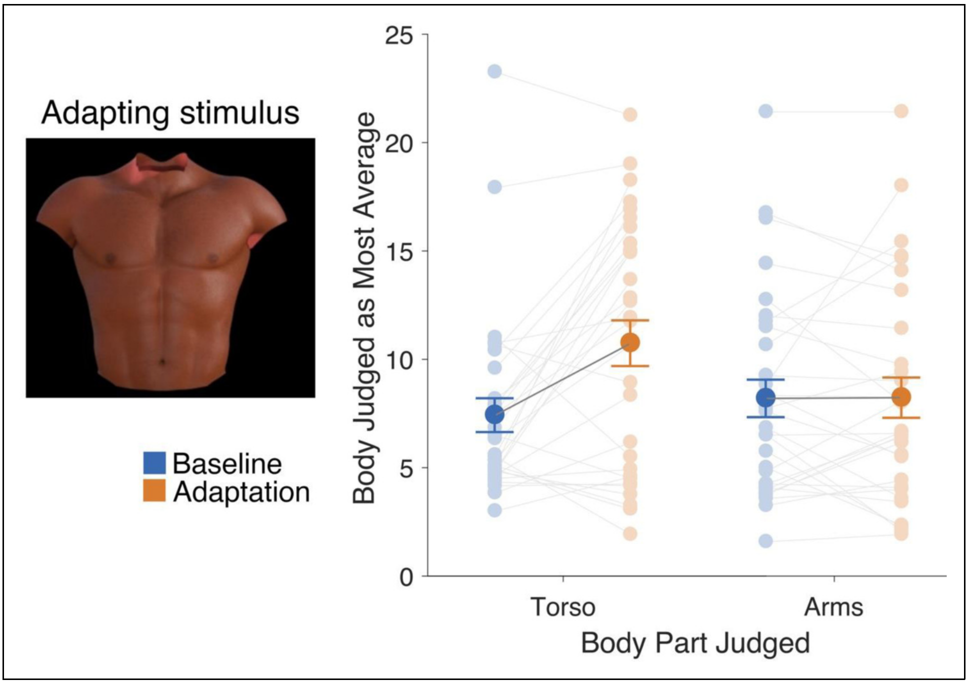

Figure 2. Results of Experiment 1 with muscular torsos as the adapting stimuli. For judgments of torso stimuli, there was a clear contrastive adaptation aftereffect, with judgments in the adaptation blocks (orange) shifted in the direction of the muscular adapting stimulus compared to baseline (blue). In contrast, no such effect was found for judgments of arm stimuli. Light-coloured points are individual participant data, while dark-coloured points are grand means. Error bars are one standard error.

adiposity adaptation in our lab (Ambroziak et al., 2019, 2023; Myga et al., 2024). In addition, before each trial a muscular adapting stimulus was shown again for an addition two seconds of ‘top up’ adaptation.

At the end of the study, participants completed the Adonis Complex Questionnaire (Pope et al., 2000; Riccobono et al., 2020), a 13-item questionnaire assessing dissatisfaction and body image concerns related to muscularity in men. The mean score was 7.4 (*SD*: 5.1).

Analysis. Analysis procedures were similar to our previous studies using body size adaptation (Ambroziak et al., 2019, 2023; Myga et al., 2024). An analysis of variance (ANOVA) was conducted including *time* (baseline, adaptation) and *body part* (torso, arm) as repeated-measured factors. The presence of adaptation aftereffects for each body part was further assessed using two-tailed paired *t*-tests to compare baseline and adaptation blocks for each body part. As measures of effect size, we report η_p^2 for *F*-tests and Cohen’s d_z for paired *t*-tests.

Stimuli and raw data are available on the Open Science Framework: https://osf.io/xkb6w/

Results and Discussion

The results from Experiment 1 are shown in Figure 2. An ANOVA showed a significant main effect of time, $F(1, 29) = 6.97, p < .02, \eta_p^2 = .194$, which was modulated by a significant interaction of time and body part, $F(1, 29) = 19.34, p < .001, \eta_p^2 = .400$. For torso judgments, there was a clear effect of adaptation, with higher scores during adaptation (*M*: 10.74, *SD*: 5.77) than at baseline (*M*: 7.43, *SD*:

4.27), $t(29) = 3.73$, $p < .001$, $d_z = 0.681$. This is a classic contrastive aftereffect, consistent with previous results showing visual aftereffects for body muscularity (Brooks et al., 2020a; Ip et al., 2024; Sturman et al., 2017). There was no significant correlation between the magnitude of the adaptation aftereffect for the arms and the Adonis Complex Questionnaire, $r(28) = -.160$, $p = .399$.

In striking contrast, however, for arm judgments there was no difference between scores during adaptation (*M*: 8.23, *SD*: 5.09) and during baseline (*M*: 8.20, *SD*: 4.74), $t(29) = 0.06$, $p = .951$, $d_z = 0.011$. Thus, aftereffects were found only for the body part (i.e., the torso) which served as the adapting stimulus.

These results provide clear evidence for body-part specificity in body-related adaptation aftereffects, consistent with other results (Bratch et al., 2021; Ip et al., 2024). Unlike those previous studies, however, the present experiment shows specificity between body parts which are both on the upper part of the body. An alternate interpretation of the results, however, could be that aftereffects might be easier to elicit for torsos than for arms, at least in the specific case of muscularity aftereffects. To address this possibility, we thus conducted a second experiment using arms as adapting stimuli. If the results of the present experiment reflect body-specific perceptual representations, the effect should reverse and aftereffects should be found for arms, but not for torsos.

Experiment 2

The second experiment was identical to the first, except that the adapting stimuli were highly muscular arms, instead of torsos.

Method

Participants. An additional 30 adult men in the UK between 22 and 40 years of age (*M*: 31.0, *SD*: 5.5) were recruited using the Prolific platform (https://www.prolific.com/). The mean score on the Adonis Complex Questionnaire was 8.5 (*SD*: 6.1).

Procedure. As noted above, the structure of this experiment was identical to Experiment 1 except that the adapting stimulus was a pair of muscular arms, rather than a muscular torso. One other difference was that while Experiment 1 was conducted in the lab, Experiment 2 was conducted online. The Gorilla platform was used in both experiments.

Results and Discussion

The results from Experiment 2 are shown in Figure 3. An ANOVA showed significant main effects of time, $F(1, 29) = 10.23$, $p < .005$, $\eta_p^2 = .261$, and of body part, $F(1, 29) = 12.09$, $p < .005$, $\eta_p^2 = .294$. These were modulated by a significant interaction of time and body part, $F(1, 29) = 21.63$, $p < .0001$, $\eta_p^2 = .427$. Critically, the nature of the effect reversed from that seen in Experiment 1. For arm judgments, there was a clear effect of adaptation, with higher scores during adaptation (*M*: 13.63, *SD*: 5.63) than at baseline (*M*: 8.16, *SD*: 5.24), $t(29) = 4.55$, $p < .0001$, $d_z = 0.831$. In contrast, for torso judgments, there was no difference between adaptation (*M*: 9.17, *SD*: 4.86) and baseline (*M*: 8.11, *SD*: 5.17), $t(29) = 1.01$, $p = .319$, $d_z = 0.185$. There was no significant correlation between the magnitude of the adaptation aftereffect for the arms and the Adonis Complex Questionnaire, $r(28) = .252$, $p = .179$.

Finally, we conducted an ANOVA across the two experiments, including adaptor type (torso vs. arm) as a between-subjects factor. There was a significant main effect of time, $F(1, 58) = 16.90$, $p < .001$, $\eta_p^2 = .226$, and a significant interaction between adaptor type and body part, $F(1, 58) = 10.08$, $p < .005$, $\eta_p^2 = .148$. There were no significant main effects of adaptor type, $F(1, 58) =$

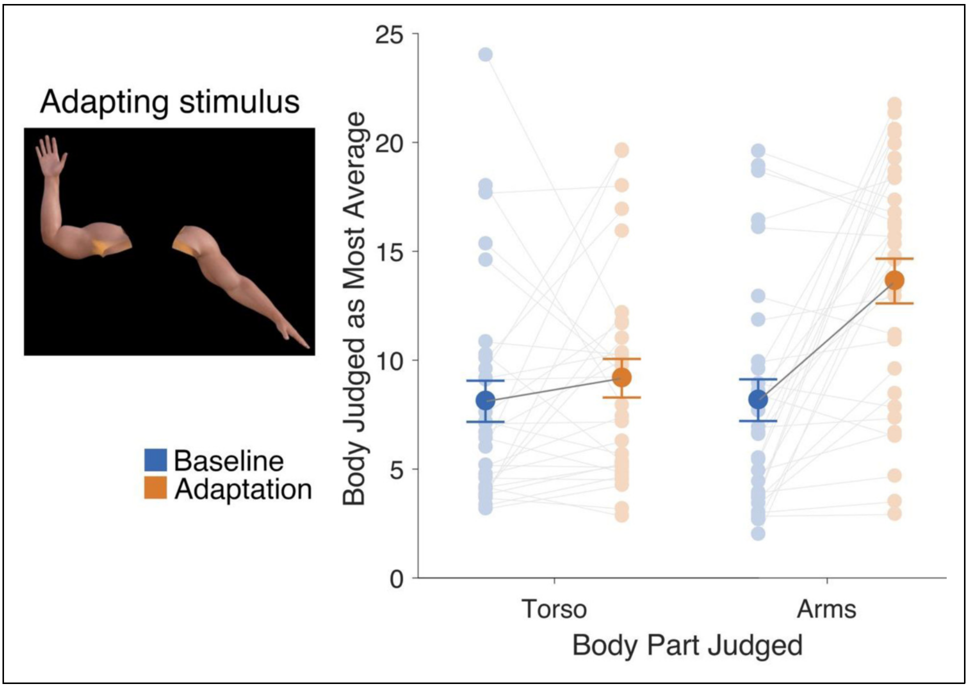

Figure 3. Results from Experiment 2 with muscular arms as the adapting stimulus. For judgments of arm stimuli, there was a clear contrastive aftereffect, with judgments during adaptation (orange) shifted towards the muscular adapting stimuli compared to baseline (blue). In contrast, no such effect was found for judgments of torso stimuli. Light-coloured points are individual participant data, while dark-coloured points are grand means. Error bars are one standard error.

1.20, $p = .278$, $\eta_p^2 = .020$, or of body part, $F(1, 58) = 1.98$, $p = .165$, $\eta_p^2 = .033$. There were no significant interactions of time and adaptor type, $F(1, 58) = 1.75$, $p = .192$, $\eta_p^2 = .029$, or of time and body part, $F(1, 58) = 0.87$, $p = .355$, $\eta_p^2 = .015$. Most importantly, there was a highly significant 3-way interaction, $F(1, 58) = 40.64$, $p < .0001$, $\eta_p^2 = .412$.

These results again show clear evidence for body-part specific adaptation aftereffects. As the results flipped from Experiment 1, this experiment shows that the effects in the previous experiment do not reflect the torso being easier to induce aftereffects for than arms. Together, the two experiments provide a double dissociation between the effects of adaptation to torsos (Experiment 1) and arms (Experiment 2).

General Discussion

The present results demonstrate a high degree of body-part specificity for visual adaptation aftereffects for body muscularity in men. When participants were adapted to muscular torsos (Experiment 1), adaptation aftereffects were found for judgments of torsos – but not for judgments of arms. Conversely, when participants were adapted to muscular arms (Experiment 2), adaptation aftereffects were found for judgements of arms – but not torsos. These results thus provide a clear double-dissociation in the effects of adaptation to muscular torsos versus arms.

Our results provide a clear replication of recent studies showing body-part specificity for body-related adaptation aftereffects (Bratch et al., 2021; Ip et al., 2024). However, the present study provides further insight into the nature of this specificity. Bratch and colleagues interpreted their results as showing limb specific representations, as adaptation to leg stimuli did not produce adaptation for arms. Our results, however, show that there is no qualitative difference between limbs and other body parts, as similar body-part specific effects were found for both arms (Experiment 2) and torsos (Experiment 1). It is important to emphasise, however, that Bratch and colleagues investigated perception of limb length, whereas the present results concern muscularity, and these two types of judgments might work very differently. The study of Ip and colleagues is much more similar to the present study in this respect. These authors, in contrast, interpreted their results as reflecting body-half specific representations (i.e., upper half vs. lower half), though they also note that their results could reflect adaptation for smaller body parts. Our results, however, show specificity comparing two body parts which are both part of the upper body half. It will be interesting in future studies to investigate how specific such effects can be. For example, while we have treated arms as single body parts, these can also be further segmented into, for example, upper arm, forearm, and hand. It is not clear whether specificity could be found at that level. However, it is worth nothing that recent neuroimaging studies have provided evidence for hand-specific visual representations in the ventral visual pathway (Bracci et al., 2010, 2012).

The body-part specificity of the present study, and other recent studies (Bratch et al., 2021; Ip et al., 2024), contrasts with other studies showing generalisation between whole bodies and faces (Ambroziak et al., in press; Cooney et al., 2015; Ghuman et al., 2010; Kessler et al., 2013; Palumbo et al., 2015) and hands (Ambroziak et al., 2023). It remains unclear why specificity is found in some cases and generality in others. One possibility is that different types of perceptual judgment about bodies may use different sorts of body representations. For example, two recent studies from our lab which have shown cross-adaptation between body parts have both used judgments of adiposity (Ambroziak et al., 2023, in press), while two other studies which have found body-part specificity have both used judgments of muscularity (Ip et al., 2024; this study).

Another possibility is that there are multiple visual representations of bodies which may differ in this respect. For example, Taylor and colleagues (2007) used functional magnetic resonance imaging (fMRI) to investigate two regions in the ventral visual pathway which have been found to be body-selective, the extrastriate body area (EBA) and the fusiform body area (FBA). Whereas the EBA appears sensitive to individual body parts, the FBA appears most sensitive to whole bodies. Similarly, while there are separate regions in the ventral visual pathway selectively for faces and for bodies (Kanwisher, 2010), there is also evidence for regions that respond most strongly when faces and bodies are presented together (Fisher & Freiwald, 2015; Harry et al., 2016; Kaiser et al., 2014). Thus, specificity and generality co-exist in the visual system. It will be interesting in future research to identify which stimuli or experimental conditions lead to more-specific or more-general visual body representations being recruited. One hint comes from the results of Ip and colleagues (2024) who found modest cross-adaptation between upper and lower body halves when only half-body stimuli were shown, but no cross-adaptation at all when full-body stimuli were presented.

The present findings of body-part specificity are consistent with other recent findings showing that specific body parts carry information about the emotional states of others (Blythe et al., 2023, in press; Ross & Flack, 2020). For example, Ross and Flack showed that removing specific body parts from stimuli showing actors displaying different emotions impaired people's ability to recognise what emotion was being displayed. Similarly, Blythe and colleagues (2023) showed that people can accurately classify the emotion being displayed by an actor even when shown only isolated body parts, such as hands, arms, and torsos. This ability was particularly strong for the hands, consistent with the results mentioned above showing hand-specific representations in the human visual system (Bracci et al., 2010, 2012).

An important limitation of the present study concerns whether the adaptation aftereffects we report occurs at a perceptual level or at a decisional level. As discussed by Storrs (2015), this is a general difficulty with nearly all studies looking at 'high-level' aftereffects, such as those for faces and bodies. Therefore, we cannot determine from the present data whether adaptation literally alters the visual appearance of muscularity or whether it alters the way in which participants make a decision about which stimulus appears more normal. Identifying methods for differentiating these interpretations across the wide range of face and body related aftereffects is thus an important goal for future research.

In conclusion, the present study shows clear body-part specificity for adaptation aftereffects for body muscularity in men. These results compliment recent findings for body-part specificity (Bratch et al., 2021; Ip et al., 2024) and provide further insight into the nature of this specificity.

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Author Contribution(s)

Wilder Daniel: Conceptualization; Formal analysis; Investigation; Methodology; Software; Writing – original draft.

Matthew R. Longo: Conceptualization; Data curation; Formal analysis; Methodology; Project administration; Software; Supervision; Visualization; Writing – review & editing.

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Declaration of Conflicting Interests

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