Visual body-size adaptation and estimation of tactile distance

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Estimating the size of bodies is crucial for interactions with physical and social environments. Body-size perception is malleable and can be altered using visual adaptation paradigms. However, it is unclear whether such visual adaptation effects also transfer to other modalities and influence, for example, the perception of tactile distances. In this study, we employed a visual adaptation paradigm. Participants were exposed to images of expanded or contracted versions of self- or other-identity bodies. Before and after this adaptation, they were asked to manipulate the width of body stimuli to appear as 'normal' as possible. We replicated an effect of visual adaptation such that the body-size selected as most 'normal' was larger after exposure to expanded and thinner after exposure to contracted adaptation stimuli. In contrast, we did not find evidence that this adaptation effect transfers to distance estimates for paired tactile stimuli delivered to the abdomen. A Bayesian analysis showed that our data provide moderate evidence that there is no effect of visual body-size adaptation on the estimation of spatial parameters in a tactile task. This suggests that visual body-size adaptation effects do not transfer to somatosensory body-size representations.

A significant proportion of the population over- or underestimate the size of their own body, believing it to be larger or smaller than it really is (Lee, Seo, Shim, & Lee, 2015; Quick et al., 2015) likely resulting in increased body dissatisfaction (Brooks, Mond, et al., 2020). This phenomenon has been linked in the literature to exposure to extreme idealized bodies (i.e., thin women's or muscular men's bodies) in the media (Bruch, 1978) and, more recently, in social media viewed on smartphone screens (Fardouly, Diedrichs, Vartanian, & Halliwell, 2015). Recently, it has been argued that the link between exposure to idealized body images in the media and mis-estimation of one's own body-size may be partially explained by visual adaptation (Brooks, Mond, et al., 2020; Challinor et al., 2017).

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The hypothesis is that viewing images of thin (or muscular) bodies in the media leads to visual adaptation such that when subsequently viewing one's own body in a mirror, it is misperceived as heavier (or less muscular) than it really is. This misperception is then internalized, leading to distortion of the internal representation of one's own body-size.

In line with this hypothesis, Rickmeyer, Hummel, Ernst, and Grabhorn (2016) have reported a reduced capacity to adapt to contracted thin bodies in individuals with *anorexia* and *bulimia nervosa*. The authors suggest that after long-term adaptation to thin body shapes during the participants' real-world experiences, additional visual adaption to thin body shapes during laboratory sessions might not be possible. Although relevant alternative explanations such as response biases could not be ruled out by the authors, this may suggest long-term changes to internal body-size representation, possibly due to disproportionate viewing of thin bodies over time.

In somatosensory tasks, enlarged spatial representations have also been linked to anorexia nervosa. Several studies have shown that tactile distances were overestimated, especially for the abdomen and the horizontal/width dimension, in a group of individuals with anorexia nervosa as compared to controls (Keizer, Smeets, Dijkerman, van Elburg, & Postma, 2012; Keizer et al., 2011; Spitoni et al., 2015). This supports the possibility that a representation that tracks spatial body dimensions might be impaired in anorexia nervosa, which in turn could affect a number of different body representations and tasks relying on an estimate of body-size (Gadsby, 2017). On the basis of the hypothesis that visual adaptation might be a causal mechanism for body-size misperceptions in eating disorders (Brooks, Mond, et al., 2020), it is thus important to test whether visual adaptation effects could also lead to changes in tactile distance estimation (TDE).

A number of studies have demonstrated adaptation to visually perceived body-size (see Brooks, Mond, et al., 2020; Challinor et al., 2017 for reviews). Prolonged exposure to contracted (or expanded) bodies results in adaptation aftereffects such that subsequently presented bodies are perceived as larger (or smaller) than they really are. This effect has been shown to affect high-level visual body representations (e.g., orientation- and image size-invariant visual object representations) and does not appear to be merely a collection of low-level (e.g., retinotopic) adaptation effects (Brooks, Clifford, Stevenson, Mond, & Stephen, 2018). Furthermore, visual adaptation can affect representations of different structural body components, such as body fat and body muscle, independently (Brooks, Keen, et al., 2020; Sturman, Stephen, Mond, Stevenson, & Brooks, 2017). Adaptation effects have also been shown to transfer between identities (Hummel, Rudolf, Untch, Grabhorn, & Mohr, 2012). However, there seems to be an identity-specific component such that adaptation effects are larger when the identity of adaptation and test stimuli is congruent (Brooks, Mond, Stevenson, & Stephen, 2016). Overall, these experimental findings demonstrate that high-level visual body-size representations adapt to recent visual input and can be quite rapidly modified.

This line of research has shown that different types of body representations can be affected by visual adaptation to body-size and shape. A recent study reported aftereffects of viewing fat and thin bodies on computer-generated test body stimuli. These aftereffects were highly similar regardless of whether the test stimuli were compared with their own body, the body of another person, or a 'normal' body (Ambroziak, Azanon, & Longo, 2019). This was interpreted as evidence that body-size adaptation affects perception of the body stimulus currently being viewed, but does not directly affect the stored internal body representation. However, it is still unclear if body-size adaptation affects the processing of information in other senses that also rely on internal representations of body-size.

A representation of one's bodily shape and size is also important for the perception of somatosensory information (Gadsby, 2017; Longo, Azanon, & Haggard, 2010; Medina & Coslett, 2010). This is, for example, important for tactile recognition and interaction with objects where one has to estimate the distance between points that are touched on the skin. The spatial relationships between different touches on the skin cannot be simply determined by activation in the primary somatosensory cortex because it contains distorted representations, known as the somatosensory homunculus (e.g., larger representation for more sensitive skin regions; Penfield & Boldrey, 1937). Thus, for perceptual estimates of spatial distance between two touches on the skin, a model of body-size and shape and a transfer function is needed to map signals from the primary somatosensory cortex to a more veridical spatial representation of the body. The generation of a model of body-size and shape is thought to involve sensory integration of information from different modalities including the somatosensory and visual systems (Longo, 2015).

Previous research has indeed shown that short-term manipulations of visual, proprioceptive, and auditory input can rescale the current body-size model and change tactile distance and haptic size estimations (Bruno & Bertamini, 2010; Tajadura-Jimenez et al., 2012; Taylor-Clarke, Jacobsen, & Haggard, 2004; de Vignemont, Ehrsson, & Haggard, 2005). For example, Taylor-Clarke et al. (2004) have shown that altering the visual experience of the body by viewing an enlarged arm or hand increases tactile distance estimates. The authors propose (p. 220) '[...] that rescaling may be particularly important for touch, because primary somatosensory cortical representation is highly plastic, varying with tactile experience and bodily changes'. This demonstrates that prior visual experience can affect somatosensory spatial representations.

Further, aftereffects for tactile distance perception have been demonstrated after tactile distance adaptation (Calzolari, Azanon, Danvers, Vallar, & Longo, 2017; Hidaka, Tucciarelli, Azanon, & Longo, 2020). However, to date it is unclear whether visual size adaptation demonstrated for whole bodies also rescales the perception of tactile distance. It is possible that viewing a contracted or expanded whole body for some time changes both the visual representation of body-size, and also transfers to size representations used for the perception of tactile distances on the abdomen. For example, after adaptation to contracted (or expanded) bodies, images of bodies are subsequently visually perceived as larger (or smaller). This might also affect a somatosensory internal mental representation of one's own body-size and hence lead to increased (or decreased) estimates of tactile distances after contracted (or expanded) body-size adaptation. Alternatively, visual exposure to contracted (or expanded) bodies might lead to a subsequent decrease (or increase) of the perceived distance between two tactile stimuli, if the participant internalizes the visual adaptation stimulus as an accurate representation of their own body, as occurred for arm and hand stimuli in a previous study (Taylor-Clarke et al., 2004). Or, it may be that simply viewing small images of bodies from a second-person perspective causes visual body-size adaptation, but has no effect on the multi-modal size representation of one's own body. If this were the case, judgements of tactile distance would remain unchanged.

In this study, we set out to investigate whether body-size modulations might transfer across different modalities and tasks. We employed a visual body-size adaptation paradigm. Before and after adapting to either thin or fat bodies participants were asked to rate the visual 'normality' of bodies and estimate the distance of two touches on the abdomen.

Methods

We employed a visual body-size adaptation paradigm similar to previous research (Brooks et al., 2019; Gould-Fensom et al., 2019) and tested the effect of body-size adaptation on the visual perception of body-size as well as tactile distance.

Participants

Sixty female Caucasian students (age range from 18 to 30 years, $M = 20.25$, $SD = 3.20$) enrolled in an undergraduate Psychology course at Macquarie University received course credit for their participation. Previous work with similar numbers of participants per experimental group found large effect sizes for the visual adaptation effect (η_p^2 between .676 and .753) (Brooks et al., 2016, 2018). We assumed that the tactile adaption effect is likely smaller. With our sample size, we have the statistical power at ~.90 to detect an effect that is approximately a fourth of the smallest found visual adaptation effect ($\eta_p^2 = .150$). All participants had normal or corrected to normal vision and gave written consent before agreeing to participate. The experiment was approved by the Macquarie University Human Research Ethics Committee and conducted in accordance with the Declaration of Helsinki.

Design

In a 2×2 factorial between-subject design, we manipulated adaptation direction (contracted vs. expanded) and adaptation identity (self vs. other). We tested 15 participants for each of the four conditions and measured two dependent variables: a visual point of subjective normality (PSN: the visual stimulus size that appeared most normal) and a tactile distance estimation (TDE: an estimate of the distance between two tactile stimuli presented on the participant's abdomen). We a priori chose to test 15 participants per condition which is similar to previous work in which visual adaptation effects were found (Brooks et al., 2016, 2018). We measured both variables before (baseline) and after an adaptation phase.

Apparatus and stimuli

We presented the visual stimuli on an AOC monitor (G2770PF) with a screen resolution of $1,920 \times 1,080$ pixels. Participants were standing for optimal stimulus delivery in the tactile task (see below), and the monitor was placed on top of a raised platform (a height-adjustable standing desk) to be at the participant's viewing height. The viewing distance was approximately 80 cm.

We created full-body stimuli, including the face, from digital photographs of each participant. In those images, participants wore grey cycling shorts and a grey singlet to ensure good visibility of the body shape. Participants removed jewellery and make-up before their photographs were taken. We asked participants to pose with a neutral expression in a standard anatomical position (standing upright, feet positioned approximately at shoulder width, arms straight at the side of the body, hands ~20 cm from the body with palms facing forward, see Figure 1A,B). We took the images in a booth painted with Munsell N5 neutral grey. The booth was illuminated with 15 high-accuracy d65 fluorescent Philips tubes mounted in high-frequency fixtures to reduce the effects of flickering. The camera (Canon EOS 70D) settings were held constant across all participants.
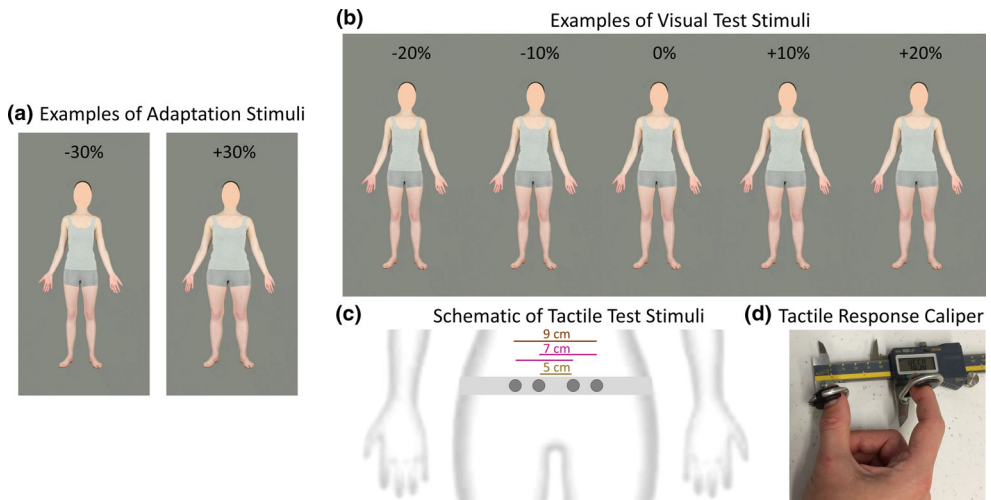
Figure 1. Methods. (A) Examples of adaptation stimuli for the contraction condition (−30%) and the expansion (+30%) conditions. (B) Five examples for the visual test stimuli at −20, −10, 0, 10, 20% size manipulation levels are shown. Faces were fully visible in the experiment. (C) Schematic of the location and distances used for tactile stimulation. Participants wore a belt with four tactile stimulators centred just below the navel with paired distances of 5, 7, and 9 cm in between. (D) Picture of calliper used to provide tactile distance estimate.

We measured weight and height to obtain a measurement of the body mass index (mean BMI = 22.85, SD = 3.41, range 16.7–33.4). Participants in 'other' conditions were assigned a body for the adaptation phase (the visual testing stimuli were always self-images) from an existing database of images collected under identical conditions. The 'other' BMIs were matched as closely as possible (within +/-0.2 kg/m^2 of the participant's BMI).

To create different body-size stimuli, we used the 'spherize' function in Adobe Photoshop to contract and expand the depicted bodies from neck to ankles with the head size and importantly also the arm/hand size unchanged. To avoid image discontinuities, we used a feathered marquee which blended the body distortions smoothly into the non-manipulated areas of the image. We created 13 test images involving spherize manipulations of between −30% and +30% in 5% steps, including the original image (0%). The bodies were formatted to a standard height of 720 pixels and a width of 320 pixels (total image size 900 × 450 pixels). We used the most extreme images (−30% and 30%) as adaptation stimuli (Figure 1A). Examples for test stimuli at ±20%, ±10%, and 0% spherize levels are depicted in Figure 1B (Brooks et al., 2016).

For tactile stimulation, we used four small electromagnetic solenoid-type stimulators (diameter: 18 mm and probe height: 12 mm, Dancer Design, St. Helens, UK; dancerdesign.co.uk) and an amplifier (TactAmp 4.2 with a D25 serial port, Dancer Design). Small solenoid stimulators have also been used in previous TDE tasks (Taylor-Clarke et al., 2004; de Vignemont et al., 2005). We attached the tactile stimulators in a row to a cloth belt (with 2, 5, and 2 cm between the tactors' probes; this allowed the delivery of tactile stimuli with 5-, 7-, and 9-cm distances along the medio-lateral body axis; Figure 1C). The tactile stimuli consisted of a 1.2 s vibration (33 Hz). We placed two further 'sham tactors' that were not connected to the amplifier on both the outer left and the outer

right side with 2-cm spacings. This way participants were not able to guess tactile distances from just feeling the location of the tactors alone. We used an electronic vernier calliper (OriginCal, iGaging, California, USA) connected via the USB port to record distance estimates for the tactile task (Figure 1D). Two finger attachments for the thumb and index finger were mounted to the two calliper sides so that participants could easily move these along using one hand only. To hide their view of the tactile stimulators and calliper, participants wore a black cape and the bottom of the cape was attached to the table.

We used MATLAB (MathWorks, Natick, MA, USA) and the Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007) to control stimulus delivery and response collection. Participants used their right hand for tactile calliper responses and the left hand to control stimulus presentation and give responses for the visual task.

Tasks

For the visual task, we measured the visual PSN we used a method of adjustment task (Brooks et al., 2019; Gould-Fensom et al., 2019). In each visual response trial, participants moved the mouse horizontally (starting position was randomized; mouse pointer was not visible) to move through the 13 possible versions of each body (see Figure 1B). The task was to select the image that looked most like their 'normal' unmanipulated images which they saw at the beginning and to change the image if it looked larger or smaller, pressing a mouse button to register their response.

For the tactile task, we used kinaesthetic TDE (Keizer et al., 2011; Le Cornu Knight, Cowie, & Bremner, 2017; Scarpina, Castelnuovo, & Molinari, 2014; Stone, Keizer, & Dijkerman, 2018). Following tactile stimulation on the abdomen, participants were instructed to set the distance with the callipers that they perceived to match the abdominal stimulus distance. This is analogous to holding one's fingers apart to say 'they are this far apart'. Once they completed their distance estimate, participants pressed a button on a small box to enter their response setting. After a one-second interval, participants were then instructed to either completely close or widen the calliper as far as they could. They then were asked to press the mouse button which initiated the next trial. The type of instruction (close vs. widen) and the start position for the next trial was randomized. There were three types of tactile trials with stimuli either 5, 7, or 9 cm apart. In half the trials, the 7-cm distance was achieved using the outer left and middle right tactile stimulator and in the other half using the outer right and middle left tactile stimulator.

Procedure

Participants were standing throughout the experiment. First, the experimenter fitted the belt around the participant's abdomen and centred the tactile stimulators just below the navel. Then, participants were shown the unchanged picture of their own body as a reference for 5 s. This was followed by task instructions and the practice phase which included four sets of the visual and tactile test stimuli. This was followed by the baseline block and then the adaptation block (Figure 2). The adaptation differed from the baseline block in the following respects: The adaptation block started with a 120 second initial adaptation period. During this time, the adaptation stimulus (contracted or expanded body of self or other) was shown. Participants were asked to simply view the image which was repositioned on the screen every 3 s (up to ±30 pixels in all directions from the

Adaptation and Test design

1. Baseline Block
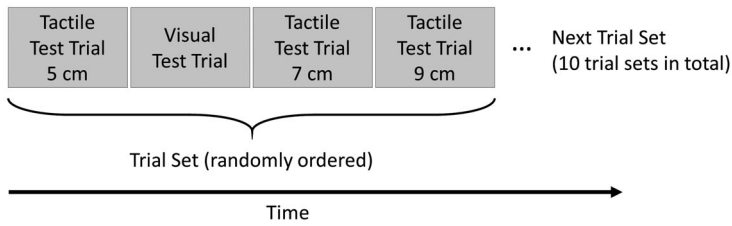
2. Adaptation Block
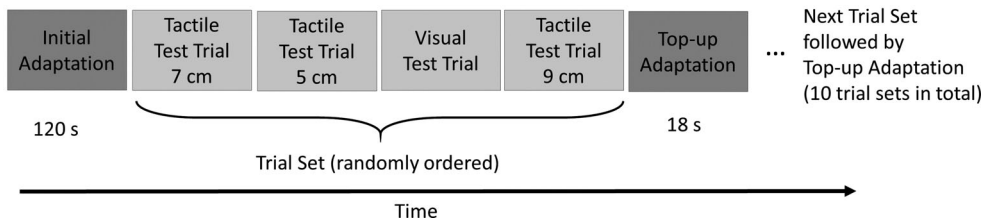
Figure 2. Adaptation and test design. The experiment consisted of a baseline and adaptation block. We used trial sets of four trials (one visual and three tactile task trials – 5, 7, and 9 cm). Ten of these trial sets were delivered during the baseline and 10 during the adaptation phase. In the adaptation phase, an initial long adaptation phase was used at the beginning (120 s), followed by 18 s top-ups before every next trial-set.

centre). After the initial adaptation, a top-up adaptation period of 18 s (refreshed and repositioned as above) was used before each set of trials.

A set of trials consisted of four trials – one of each trial type (one visual and each of the three tactile tasks – 5, 7, and 9 cm; the order of the two different 7-cm trials – outer left and outer right – was randomized within the baseline and adaptation block) presented in random order (ADBC, CBDA, ACBD, etc.). There were 10 trial sets (40 trials in total) in both the adaptation and baseline block. A short (50 ms) sound was played before each trial (a low tone for the tactile task and a high tone for the visual task) to prepare participants. Each trial started 500 ms after the sound.

The experiment took place 2–7 days after the body photographs were taken. The experimental session started with an equipment setup and a short practice phase to familiarize the participants with the procedure, followed by baseline testing, adaptation, and post-adaptation testing. The experiment took approximately 30 min to complete.

Statistical analysis

We used R for data processing and visualization including the package ggplot2 (Wickham, 2016) and JASP (www.jasp-stat.org) for statistical data analysis.

We calculated the PSN and TDE change after adaptation compared to the baseline for each condition and participant. For the PSN change, we calculated the difference between adaptation and baseline to obtain a value expressed in units of image expansion (%). For the TDE, we calculated the difference between adaptation minus baseline. To analyse

visual PSN and TDE changes, we used 2×2 between-subject ANOVA with the factors adaptation direction (contracted vs. expanded) and adaptation identity (self vs. other). Our primary interest was the effect of adaption (main effect of adaptation direction). In addition, we also explored if adaptation identity (self vs. other) modulates this effect (interaction between adaptation direction and adaptation identity). The threshold for statistical significance was set at $p < .05$.

In addition, to verify that our participants were able to discriminate different tactile distances, we also analysed baseline TDE values using a one-way within-subject ANOVA with the factor tactile distance (5 cm, 7 cm, 9 cm).

To specifically follow-up null findings that are of theoretical interest, we used a Bayesian analysis (Dienes, 2014). We calculated Bayes factors (BF) using the JASP default prior (Cauchy prior, $r = .707$). We take a BF < 1/3 to indicate moderate evidence for the null hypothesis (and BF < 1/10 as strong evidence) and a BF > 3 to indicate moderate evidence for the alternative hypothesis (and BF > 10 as strong evidence), whereas BFs between 1/3 and 3 would indicate a lack of sensitivity to support one hypothesis over the other (Jeffreys, 1961; Lee & Wagenmakers, 2014).
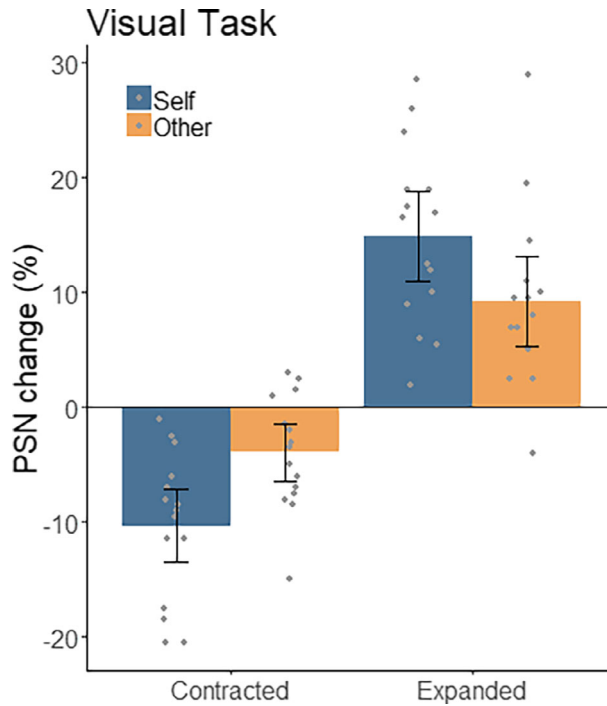
Results

As expected, for the visual task, we found a main effect of adaptation direction [$F(1, 56) = 119.77, p < .001, \eta_p^2 = 0.681$] with negative values for the contracted condition and positive values for the expanded condition (Figure 3). Furthermore, we found a significant interaction between adaptation direction and adaptation identity [$F(1, 56) = 11.96, p = .001, \eta_p^2 = .176$] with larger adaptation effects for self than for other. These results replicate previous visual body adaptation findings including a very similar effect size for the main effect (Brooks et al., 2016, 2018).

For the baseline TDE values (Figure 4), we found a numerical increase from the 5-cm, to the 7-cm, to the 9-cm distance, and a significant main effect of distance [$F(2, 118) = 94.63, p < .001, \eta_p^2 = .616$]. This result shows that participants on average gave distance-specific responses and thus could perceive the distances as different. Across all distances, we observed an underestimation compared to actual distance at each level which has previously also been reported for control samples (Keizer et al., 2012; Longo, Lulciuc, & Sotakova, 2019). As in the previous research, we collapsed the data across the three distances to investigate effects of our manipulations on TDE.

We did not find significant adaptation effects for the tactile task measure (Figure 5). TDE values relative to baseline did not differ significantly between the contracted and expanded condition [main effect adaptation direction: $F(1, 56)=0.847, p = .361, \eta_p^2 = .015$]. Furthermore, we found no significant interaction between adaptation direction and adaptation identity [$F(1, 56) = 0.039, p = .845, \eta_p^2 = .001$].[1]

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[1] *In addition and not predicted by previous work, we found a significant main effect for the adaption identity [F(1, 56) = 4.43, p = .040, η_p^2 = .073]. Further exploring what may underlie this main effect, we found that both other groups had smaller baseline mean tactile estimates (thin-other TDE$_{baseline}$ = 4.542, fat-other TDE$_{baseline}$ = 4.453) compared to the self-groups (thin-self TDE$_{baseline}$ = 5.052, fat-self TDE$_{baseline}$ = 5.270). After adaptation, the values for the other-group were larger (thin-other TDE$_{adapted}$ = 4.610, fat-other TDE$_{adapted}$ = 4.652) and for the self-group smaller (thin-self TDE$_{adapted}$ = 4.699, fat-self TDE$_{adapted}$ = 5.120) compared to baseline. Thus, the groups were more similar in their estimation after adaptation, likely due to a regression toward the mean effect (Stigler, 1997) or alternatively because they had more practice with the task. Thus, the group baseline differences, which appear to be an anomaly of sampling, and which were not present in post-adaptation data, may underlie this observed main effect of adaptation identity.*

Figure 3. Visual task results. Change of point of subjective normality (PSN) relative to baseline for contracted and expanded body-size adaptation conditions for self (blue) and other (yellow) adaptation images. All test stimuli were self-identity. Grey dots represent individual data. Error bars represent 95% confidence intervals.

This result could, however, also be due to the fact that our methods were not sensitive enough to detect a potential smaller effect ($\eta_p^2 < .150$). Given that it involves transfer of the effect between two separate sensory modalities, any adaptation effect in the tactile task would likely be smaller than the clearly present adaptation effect in the visual task. Furthermore, the tactile data would be expected to be noisier as humans generally perceive relative distance and size with greater precision in the visual than in the haptic modality (Ernst & Banks, 2002).

To evaluate whether our data were precise enough to provide evidence for the null hypothesis, we combined the data across all groups (Figure 6) and conducted a Bayesian analysis (Dienes, 2014). We combined the data by multiplying all effects that we expected based on visual adaptation to go in the negative direction by −1 (the visual data for the contracted condition and the tactile data for the expanded condition). Thus, the hypothesized change due to adaptation effects for both contracted and expanded conditions was subsequently in the positive direction.

As expected for the visual data, we found strong evidence for an adaptation effect (BF = 7.73×10^{10}). However, for the tactile data, we found moderate evidence for the null hypothesis (BF = 0.209). This provides support for the idea that visual body-size adaptation does not influence TDEs on the abdomen under our experimental conditions.

TDE baseline data
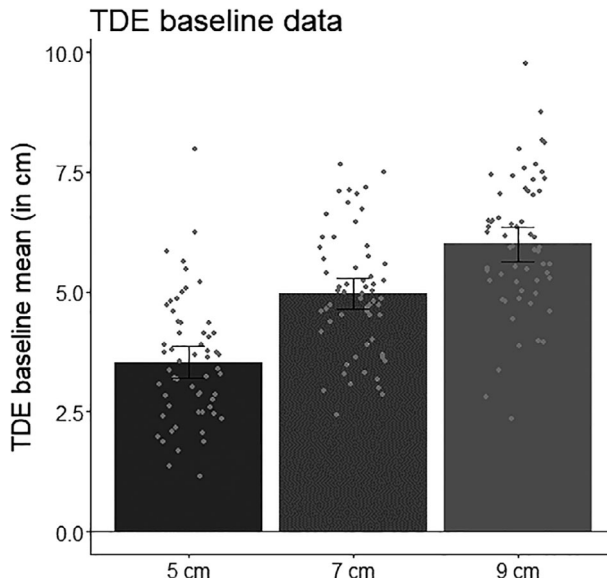
Figure 4. Tactile baseline estimates. Tactile distance estimates (TDE) for the baseline (in cm). This shows estimate differences between the distance conditions and some underestimation of tactile distance. Grey dots represent individual data. Error bars represent 95% confidence intervals.

Discussion

We were able to replicate the pattern for body-size aftereffects in the visual domain (Brooks et al., 2016). We found a significant difference for the visual PSN between adaptation for contracted and expanded bodies, with an average shift of PSN in the negative direction for contracted, and in the positive direction for expanded body adaptation stimuli, relative to baseline. Replicating a previous finding (Brooks et al., 2016), we also found that adaptation effects were larger for congruent identity (i.e., adapting to self-images and testing with self-images) than for incongruent identity (i.e., adapting to other-images and testing with self-images) conditions.

In contrast, we did not find effects of visual adaptation on tactile distance perception. Neither adaptation to contracted or expanded other-body stimuli, nor of self-body stimuli, resulted in significant adaptation effects on TDEs in the expected (or opposite) directions. Furthermore, a Bayesian analysis on the data pooled across conditions provides strong evidence for an effect of visual body-size adaptation for the visual task and moderate evidence that there is no effect due to adaptation in the tactile task.

On the basis of these analyses, we conclude that visual body-size adaptation effects do not transfer to somatosensory body-size representations. It is possible that for a manipulation of visual body information to have an effect on somatosensory representations, the body has to be viewed in a certain context that promotes associations between the visual stimulus and somatosensory processing of one's own body. Context factors that could matter are the size of the stimuli (our stimuli were smaller than the actual body in contrast to previous work using a life-like stimulus size) and visual perspective (our stimuli were viewed from a second-person perspective in contrast to previous work using a first-person perspective) (Taylor-Clarke et al., 2004). Furthermore, in the study by Taylor-Clarke et al. (2004), participants viewed a video-projection of their own hand. Although it
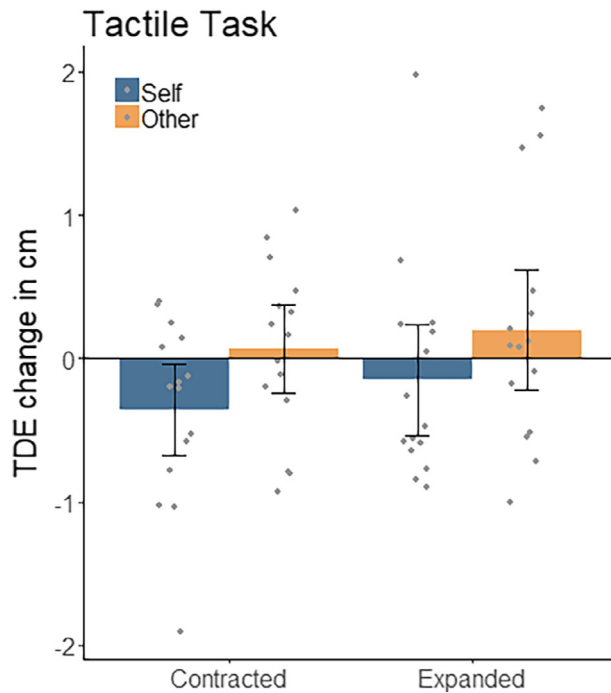
Figure 5. Tactile task results. Change in tactile distance estimation (TDE) relative to baseline for contracted and expanded body-size adaptation conditions for self (blue) and other (yellow) adaptation images. Grey dots represent individual data. Error bars represent 95% confidence intervals.

was kept relatively still, it is possible that additional synchronous stimulation (synchronous movement or touch) further helped to link visual and somatosensory bodily signals.

Indeed, an effect of the synchrony of touch on object size estimations has been shown in a rubber hand illusion study (Bruno & Bertamini, 2010). In this study, participants viewed artificial hands that were either larger or smaller than their own hand, which was hidden from view. Both hands were then stroked either synchronously or asynchronously, and the experiment tested the effect of these conditions on the haptic object size perception of the size of small discs. They found a significant interaction between the hand and synchrony conditions with larger object size estimates for the larger hand compared to the smaller hand after the synchronous, but not after the asynchronous condition. This suggests that the synchrony of multisensory information contributes to an internal body model that is used as a spatial reference for haptic size perception.

These findings are generally in line with numerous studies using bodily illusions that have shown that specific contexts that promote the association of visual and somatosensory spatial information, such as visual perspective, mirrors, and multisensory stimulation, can increase embodiment and spatial interactions between vision and touch (Aspell, Lenggenhager, & Blanke, 2009; Banakou, Groten, & Slater, 2013; Maravita, Spence, Sergent, & Driver, 2002; Pavani, Spence, & Driver, 2000; Petkova, Khoshnevis, & Ehrsson, 2011; Zopf, Savage, & Williams, 2010). In future research, it will be important to test whether such conditions would also lead to potential transfer of adaptation effects
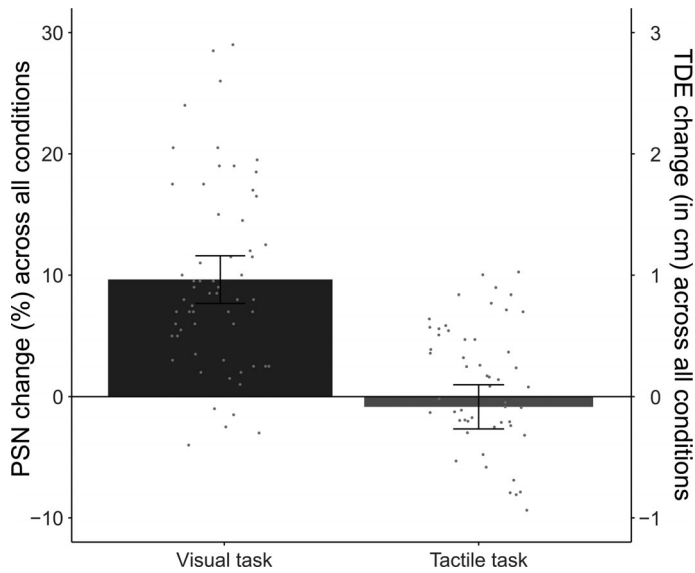
Figure 6. Visual and tactile results combined across conditions and replotted. We combined the data (expected direction positive) across all contracted and expanded conditions. While there was strong evidence for a change in visual point of subjective normality (PSN, dark grey) due to adaptation, our Bayes factor (BF) analysis provides moderate evidence that adaptation has no effect on tactile distance estimation (TDE, light grey); (BF PSN $= 7.73 \times 10^{10}$, BF TDE $= 0.209$). Grey dots represent individual data. Error bars represent 95% confidence intervals.

between modalities. Importantly, as far as we know previous effects of visual signals on TDE have only been shown for hands and arms. It would thus be important to conduct more studies on other parts of the body, especially body parts of one's own body typically have less visual exposure to and which are important for body image disturbance, such as the middle part of the body.

Our findings appear to cast doubt on the idea that media exposure of contracted bodies could be a mechanism explaining the findings with respect to TDE in Anorexia Nervosa. Although our findings do not provide direct evidence against the hypothesis that visual adaptation may contribute to body-size misperception in eating disorders and other instances of body image distortions (Brooks, Mond, et al., 2020), our results do suggest that at alternative explanations for the findings in the somatosensory domain are needed. For example, it is possible that individuals with eating disorders are relatively more reliant on distorted somatosensory representations (Longo, 2015), potentially due to a change in how spatial visual and somatosensory bodily signals are integrated (Zopf, Contini, Fowler, Mondraty, & Williams, 2016).

Furthermore, our and previous research (Ambroziak et al., 2019) suggests that visual body-size adaptation does not directly affect visual or somatosensory internal body-size representations. However, it may be the case that any transfer of body misperception from the visual system to one's internal body representation requires the visually adapted individual to view their own body (e.g., in a mirror) while visually adapted to extreme body types. Thus, over time, the internal representation of one's own body may change. More research is needed to understand the role of changes in visual and somatosensory spatial body representations and their integration to further understand body

misperceptions in clinical disorders. Furthermore, in future research it will be interesting to investigate how the size of the visual aftereffect might be related to specific traits such as body dissatisfaction and body shape concern.

In conclusion, we replicated the effects of visual body-size adaptation, which leads to significant misperceptions of one's visual body-size. We also confirmed that these effects are larger after adaptation to one's own body compared to another body. In contrast, our study provides evidence that this effect does not transfer to misperceiving the spatial distance between two touches on the abdomen. While our study is analogous to viewing thin or large bodies on TV, computer monitor, or smartphone screen, future research could test whether promoting the link between visual and somatosensory body signals either via mirrors, first-person perspective, realistic body-size, or multisensory stimulation might lead to a transfer of visual adaptation effects across different modalities.

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Conflicts of interest

All authors declare no conflict of interest.

Author contributions

Regine Zopf (Conceptualization; Formal analysis; Funding acquisition; Methodology; Supervision; Visualization; Writing – original draft) Veronika Kosourikhina (Data curation; Formal analysis; Visualization) Kevin R. Brooks (Conceptualization; Funding acquisition; Methodology; Writing – review & editing) Vince Polito (Conceptualization; Funding acquisition; Methodology; Writing – review & editing) Ian D. Stephen (Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Writing – review & editing).

Data availability statement

Our data and analysis scripts can be found on the Open Science Framework (OSF): https://osf.io/ad2yz/.

References

Ambroziak, K. B., Azanon, E., & Longo, M. R. (2019). Body size adaptation alters perception of test stimuli, not internal body image. *Frontiers in Psychology*, *10*, 2598. https://doi.org/10.3389/fpsyg.2019.02598

Aspell, J. E., Lenggenhager, B., & Blanke, O. (2009). Keeping in touch with one's self: Multisensory mechanisms of self-consciousness. *PLoS One*, *4*(8), e6488. https://doi.org/10.1371/journal.pone.0006488

Banakou, D., Groten, R., & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National*

Academy of Sciences of the United States of America, *110*, 12846–12851. https://doi.org/10.1073/pnas.1306779110

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, *10*, 433–436. https://doi.org/10.1163/156856897X00357

Brooks, K. R., Baldry, E., Mond, J., Stevenson, R. J., Mitchison, D., & Stephen, I. D. (2019). Gender and the body size aftereffect: Implications for neural processing. *Frontiers in Neuroscience*, *13*, 1100. https://doi.org/10.3389/fnins.2019.01100

Brooks, K. R., Clifford, C. W. G., Stevenson, R. J., Mond, J., & Stephen, I. D. (2018). The high-level basis of body adaptation. *Royal Society Open Science*, *5*, 172103. https://doi.org/10.1098/rsos.172103

Brooks, K. R., Keen, E., Sturman, D., Mond, J., Stevenson, R. J., & Stephen, I. D. (2020). Muscle and fat aftereffects and the role of gender: Implications for body image disturbance. *British Journal of Psychology*, *111*, 742–761. https://doi.org/10.1111/bjop.12439

Brooks, K. R., Mond, J., Mitchison, D., Stevenson, R. J., Challinor, K. L., & Stephen, I. D. (2020). Looking at the figures: Visual adaptation as a mechanism for body-size and -shape misperception. *Perspectives on Psychological Science*, *15*(1), 133–149. https://doi.org/10.1177/1745691619869331

Brooks, K. R., Mond, J. M., Stevenson, R. J., & Stephen, I. D. (2016). Body image distortion and exposure to extreme body types: Contingent adaptation and cross adaptation for self and other. *Frontiers in Neuroscience*, *10*, 334. https://doi.org/10.3389/fnins.2016.00334

Bruch, H. (1978). *The golden cage: The enigma of anorexia nervosa*. Cambridge, MA: Harvard University Press.

Bruno, N., & Bertamini, M. (2010). Haptic perception after a change in hand size. *Neuropsychologia*, *48*, 1853–1856. https://doi.org/10.1016/j.neuropsychologia.2010.01.006

Calzolari, E., Azanon, E., Danvers, M., Vallar, G., & Longo, M. R. (2017). Adaptation aftereffects reveal that tactile distance is a basic somatosensory feature. *Proceedings of the National Academy of Sciences of the United States of America*, *114*, 4555–4560. https://doi.org/10.1073/pnas.1614979114

Challinor, K. L., Mond, J., Stephen, I. D., Mitchison, D., Stevenson, R. J., Hay, P., & Brooks, K. R. (2017). Body size and shape misperception and visual adaptation: An overview of an emerging research paradigm. *Journal of International Medical Research*, *45*, 2001–2008. https://doi.org/10.1177/0300060517726440

de Vignemont, F., Ehrsson, H. H., & Haggard, P. (2005). Bodily illusions modulate tactile perception. *Current Biology*, *15*, 1286–1290. https://doi.org/10.1016/j.cub.2005.06.067

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, *5*, https://doi.org/10.3389/fpsyg.2014.00781

Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, *415*, 429–433. https://doi.org/10.1038/415429a

Fardouly, J., Diedrichs, P. C., Vartanian, L. R., & Halliwell, E. (2015). Social comparisons on social media: The impact of Facebook on young women's body image concerns and mood. *Body Image*, *13*, 38–45.

Gadsby, S. (2017). Distorted body representations in anorexia nervosa. *Consciousness and Cognition*, *51*, 17–33. https://doi.org/10.1016/j.concog.2017.02.015

Gould-Fensom, L., Tan, C. B. Y., Brooks, K. R., Mond, J., Stevenson, R. J., & Stephen, I. D. (2019). The thin White Line: Adaptation suggests a common neural mechanism for judgments of Asian and Caucasian body Size. *Frontiers in Psychology*, *10*, 2532. https://doi.org/10.3389/fpsyg.2019.02532

Hidaka, S., Tucciarelli, R., Azanon, E., & Longo, M. R. (2020). Tactile distance adaptation aftereffects do not transfer to perceptual hand maps. *Acta Psychologica*, *208*, 103090. https://doi.org/10.1016/j.actpsy.2020.103090

Hummel, D., Rudolf, A. K., Untch, K. H., Grabhorn, R., & Mohr, H. M. (2012). Visual adaptation to thin and fat bodies transfers across identity. *PLoS One*, *7*(8), e43195. https://doi.org/10.1371/journal.pone.0043195

Jeffreys, H. (1961). *The theory of probability* (3rd ed.). Oxford, UK: Oxford University Press.

Keizer, A., Smeets, M. A., Dijkerman, H. C., van den Hout, M., Klugkist, I., van Elburg, A., & Postma, A. (2011). Tactile body image disturbance in anorexia nervosa. *Psychiatry Research*, *190*, 115–120. https://doi.org/10.1016/j.psychres.2011.04.031

Keizer, A., Smeets, M. A., Dijkerman, H. C., van Elburg, A., & Postma, A. (2012). Aberrant somatosensory perception in Anorexia Nervosa. *Psychiatry Research*, *200*, 530–537. https://doi.org/10.1016/j.psychres.2012.05.001

Kleiner, M., Brainard, D., Pelli, D., Ingling, A., Murray, R., & Broussard, C. (2007). What's new in Psychtoolbox-3. *Perception*, *36*, 1–16.

Le Cornu Knight, F., Cowie, D., & Bremner, A. J. (2017). Part-based representations of the body in early childhood: Evidence from perceived distortions of tactile space across limb boundaries. *Developmental Science*, *20*(6), e12439. https://doi.org/10.1111/desc.12439

Lee, K. M., Seo, M. S., Shim, J. Y., & Lee, Y. J. (2015). Body weight status misperception and its association with weight control behaviours, depressive mood and psychological distress in nulliparous normal-weight young women. *Annals of Human Biology*, *42*, 528–532. https://doi.org/10.3109/03014460.2015.1006139

Lee, M. D., & Wagenmakers, E.-J. (2014). *Bayesian cognitive modeling: A practical course*. Cambridge, UK: Cambridge University Press.

Longo, M. R. (2015). Implicit and explicit body representations. *European Psychologist*, *20*(1), 6–15. https://doi.org/10.1027/1016-9040/a000198

Longo, M. R., Azanon, E., & Haggard, P. (2010). More than skin deep: Body representation beyond primary somatosensory cortex. *Neuropsychologia*, *48*, 655–668. https://doi.org/10.1016/j.neuropsychologia.2009.08.022

Longo, M. R., Lulciuc, A., & Sotakova, L. (2019). No evidence of tactile distance anisotropy on the belly. *Royal Society Open Science*, *6*, 180866. https://doi.org/10.1098/rsos.180866

Maravita, A., Spence, C., Sergent, C., & Driver, J. (2002). Seeing your own touched hands in a mirror modulates cross-modal interactions. *Psychological Science*, *13*(4), 350–355. https://doi.org/10.1111/j.0956-7976.2002.00463.x

Medina, J., & Coslett, H. B. (2010). From maps to form to space: Touch and the body schema. *Neuropsychologia*, *48*, 645–654. https://doi.org/10.1016/j.neuropsychologia.2009.08.017

Mohr, H. M., Rickmeyer, C., Hummel, D., Ernst, M., & Grabhorn, R. (2016). Altered visual adaptation to body shape in eating disorders: Implications for body image distortion. *Perception*, *45*(7), 725–738.

Pavani, F., Spence, C., & Driver, J. (2000). Visual capture of touch: Out-of-the-body experiences with rubber gloves. *Psychological Science*, *11*, 353–359. https://doi.org/10.1111/1467-9280.00270

Penfield, W., & Boldrey, E. (1937). Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. *Brain*, *60*(4), 389–443. https://doi.org/10.1093/brain/60.4.389

Petkova, V. I., Khoshnevis, M., & Ehrsson, H. H. (2011). The perspective matters! Multisensory integration in ego-centric reference frames determines full-body ownership. *Frontiers in Psychology*, *2*, 35. https://doi.org/10.3389/fpsyg.2011.00035

Quick, V., Nansel, T. R., Liu, D., Lipsky, L. M., Due, P., & Iannotti, R. J. (2015). Body size perception and weight control in youth: 9-year international trends from 24 countries. *International Journal of Obesity*, *2005*, 988–994.

Scarpina, F., Castelnuovo, G., & Molinari, E. (2014). Tactile mental body parts representation in obesity. *Psychiatry Research*, *220*, 960–969. https://doi.org/10.1016/j.psychres.2014.08.020

Spitoni, G. F., Serino, A., Cotugno, A., Mancini, F., Antonucci, G., & Pizzamiglio, L. (2015). The two dimensions of the body representation in women suffering from Anorexia Nervosa. *Psychiatry Research*, *230*, 181–188. https://doi.org/10.1016/j.psychres.2015.08.036

Stigler, S. M. (1997). Regression towards the mean, historically considered. *Statistical Methods in Medical Research*, *6*, 103–114. https://doi.org/10.1177/096228029700600202

Stone, K. D., Keizer, A., & Dijkerman, H. C. (2018). The influence of vision, touch, and proprioception on body representation of the lower limbs. *Acta Psychologica*, *185*, 22–32. https://doi.org/10.1016/j.actpsy.2018.01.007

Sturman, D., Stephen, I. D., Mond, J., Stevenson, R. J., & Brooks, K. R. (2017). Independent aftereffects of fat and muscle: Implications for neural encoding, body space representation, and body image disturbance. *Scientific Reports*, 7, 40392. https://doi.org/10.1038/srep40392

Tajadura-Jimenez, A., Valjamae, A., Toshima, I., Kimura, T., Tsakiris, M., & Kitagawa, N. (2012). Action sounds recalibrate perceived tactile distance. *Current Biology*, *22*(13), R516–R517. https://doi.org/10.1016/j.cub.2012.04.028

Taylor-Clarke, M., Jacobsen, P., & Haggard, P. (2004). Keeping the world a constant size: Object constancy in human touch. *Nature Neuroscience*, *7*(3), 219–220. https://doi.org/10.1038/nn1199

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Berlin, Germany: Springer-Verlag.

Zopf, R., Contini, E., Fowler, C., Mondraty, N., & Williams, M. A. (2016). Body distortions in Anorexia Nervosa: Evidence for changed processing of multisensory bodily signals. *Psychiatry Research*, *245*, 473–481. https://doi.org/10.1016/j.psychres.2016.09.003

Zopf, R., Savage, G., & Williams, M. A. (2010). Crossmodal congruency measures of lateral distance effects on the rubber hand illusion. *Neuropsychologia*, *48*, 713–725. https://doi.org/10.1016/j.neuropsychologia.2009.10.028