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Research report

# Underestimation of human hand density

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ABSTRACT

Our body is a 3D object, with physical properties such as volume, weight and density. Our brain has to represent these physical properties in the perception of one's own body and body parts. It has been shown that we have a distorted representation of hand size and hand weight. In this study, we investigated the perception of hand volume without experimental alterations. We found that people overestimate the volume of their hand on average by 24%, relative to its actual volume, and we replicated the hand weight underestimation by 25% relative to its actual weight. With a precise estimation of perceived hand volume and hand weight, we calculated perceived hand density. The mean perceived hand density was .75 g/cc, comparable to foam beads, an underestimation of 31% of actual hand density. Our findings suggest that the brain maintains a stable representation of hand density at a low level, with perceived hand weight and volume adjusting accordingly, rather than being estimated independently. Our results add to a body of evidence showing that the representation of our body parts is inherently distorted. This study contributes to the understanding of how volume, weight and density are estimated in the perception of body parts, and the relationship between the representations of physical bodily properties.



## 1. Introduction

Our body is a 3D volumetric physical object, and like any other object, it has measurable properties such as size, volume, weight and density. Yet, the way we perceive the physical properties of our body parts is quite different from the way we perceive the physical properties of any other objects in the world. We are fairly accurate in perceiving the size of objects (Norman et al., 2022), even though it can be influenced by other properties, such as orientation (Shepard, 1990; Tyler, 2011), its relative size to another object (Gentaz & Hatwell, 2004) or how familiar they are (Maltz et al., 2021). A key aspect of how we perceive our body parts lies in the presence

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of a dedicated body map within the brain, something unique to our own bodies and not applicable to external objects. This internal map consistently displays systematic distortions that are reliably observed across healthy individuals (Longo, 2017, 2022). In fact, when perceiving our own bodies, we experience consistent distortions in the perceived size (Linkenauger et al., 2015; Longo et al., 2015; Longo & Haggard, 2010), volume (Sadibolova et al., 2019) and weight (Ferrè et al., 2023) of body parts (Sadibolova et al., 2019).

Perception of hand size and shape is systematically distorted, with fingers perceived to be 20–30% shorter than their actual length, while hand width is perceived to be 60–80% wider than it truly is (Longo & Haggard, 2010). It has also been shown that there is a gradient of finger length underestimation, with the little finger being the most underestimated and the thumb the least. Critically, in a case of congenital limb absence, these distortions still occur (Longo et al., 2012), indicating that the shape and size of phantom limbs are represented in a consistent and potentially innate configuration, even without the limb itself or any visual or somatosensory input from it. Perception of body part length is also distorted: the actual length tends to be overestimated for less sensitive areas, such as the arms, legs, and torso (Linkenauger et al., 2015; Sadibolova et al., 2019). Similarly, we have demonstrated that we significantly and systematically underestimate the weight of our own hand, perceiving it to be 49% lighter than its actual weight (Ferrè et al., 2023). Taken together, these studies indicate that we have a heavily distorted perception of our hand.

Our body has physical properties such as volume, weight and density. However, no receptors can directly convey these properties; instead, our central nervous system processes different types of information to construct our perception of them. Volume, weight and density are interconnected concepts, as we rely on one to estimate the others. That is, we estimate density based on volume and weight, or infer volume from weight and density. While this relationship is well-established for the physical properties of the body, it remains unclear whether similar principles apply to how we *perceive* these properties, and whether there is a direct relationship between perceived volume, perceived weight and perceived density. To investigate this, it is essential to establish a baseline for perceived hand volume. Recent findings suggest that alterations in the perception of hand size change weight estimation: when we perceive a larger hand, we perceive its weight as being closer to its actual weight (less underestimation) than when we perceive a shrunken hand (more underestimation) (Cadete et al., 2025). In that study, magnifying and minifying mirrors were used to induce the feeling of having an enlarged, a normal and a shrunken hand. Perceived hand weight was quantified using a psychophysical staircase procedure, which showed that the hand was consistently perceived as lighter than its actual weight across all hand size manipulations. However, the shrunken hand was perceived as significantly lighter than the enlarged hand. This pattern of results is coherent with a constant density model: when experiencing a change in hand size, perceived hand weight is estimated as if the hand's density remains constant. This means that a larger hand would be perceived as heavier because it would contain more of the same "hand stuff" rather than dispersing the same mass over a larger area. This constant-density model helps explain how size, weight, and density are integrated in the perception of our own hand.

Here we systematically investigated the perceived volume, weight and density of the hand. To determine perceived hand volume, we employed a psychophysical staircase procedure in which participants judged whether the volume of a wooden block was smaller or larger than their left hand on each trial. Using cubes allowed us to create an abstract measure of hand volume, independent of the hand's shape. For perceived hand weight, we replicated the weight estimation task developed by Ferrè et al. (2023). This approach enabled us to analyse any correlation between perceived hand volume and weight and to calculate perceived hand density, using the mathematical formula of density as mass divided by volume.

## 2. Methods

### 2.1. Participants

Thirty people ($M \pm SD = 30.3 \pm 9.4$ years; 22 females, 8 males) participated after giving written informed consent. All but one participant were right-handed, as assessed by the Edinburgh Inventory (Oldfield, 1971) ($M \pm SD = 75.4 \pm 6.1$ range: −5.3 to 100). All procedures were approved by the School of Psychological Sciences Research Ethics Committee at Birkbeck, University of London and were consistent with the principles of the Declaration of Helsinki.

Ferrè et al. (2023) showed perceived hand weight is underestimated, $t(19) = -5.75$, $p < .0001$, $d = 1.285$. In this study, we aimed at replicating this finding, while adding a task for perceived hand volume. A power analysis using G*Power 3.1 Faul et al. (2007), with a 2-tailed alpha of .05 and power of .95 indicated that 11 participants were required, when considering the effect size of $d = 1.285$. As we are adding a volume task to the procedure, a sample size of 30 should be well powered to replicate the underestimation of hand weight and to find the estimation of perceived hand volume as a ratio of actual hand volume.

### 2.2. Procedure

There were a total of 4 blocks, 2 blocks for hand volume estimation, and 2 blocks for hand weight estimation, which were counterbalanced across participants in ABBA style. Each block had a total of 30 trials, which resulted in a total of 120 trials. Each block had two interleaved psychophysical staircases of 15 steps each, using the QUEST algorithm (Watson & Pelli, 1983) implemented in the PsychToolbox (Brainard, 1997) for MATLAB (Mathworks, Natick, MA).

### 2.3. Perceived hand weight

To measure perceived hand weight, we used the methods and the psychophysical matching task we developed in a previous study (Ferrè et al., 2023).

The participant sat on a chair with their left arm resting on two cushions, one below the forearm and another below the hand, leaving the wrist area available for the experimenter to place the weights stimuli. Both hands were hidden from their view. Before the task and every 15 trials, the participant hung their left hand freely to feel its weight, for 30 s. The experimenter then placed their hand back on the cushion, to begin the weight trials. In each trial, the weight was hung onto the hook attached to the wristband (Senshi, Japan), strapped around the participant's left hand (see Fig. 1A). The weights were made of plastic bags with rice in them. The participant was asked to estimate if the weight they felt pulling on their wrist was heavier or lighter than the experienced weight of their left hand. They responded by saying ‘lighter’ or ‘heavier’.

The wristband and hook weighed 76.5 g. The bags were thus filled with rice so that the total weight suspended from the wrist produced 16 weights, logarithmically spaced between 100 and 600 g, rounded to the nearest gram. These values were (in grams): 100, 113, 127, 143, 161, 182, 205, 231, 260, 293, 330, 372, 419, 472, 532, 600. For the hand weight estimations, the two QUEST staircases were given initial estimates of perceived hand weight that were either 200 g more than (i.e., 609.6 g) or less than (i.e., 209.6 g) the average hand weight (409.6 g) reported in a previous study (Kaye & Konz, 1986). On each trial, QUEST suggested which of the available stimuli to present based on a Bayesian analysis of the responses on the previous trials together with the initial estimate. The two staircases alternated across trials, in each block. Though the two staircases started with different prior estimates of hand weight, they quickly converged on a common estimate of perceived hand weight (as shown in Fig. 1C).

### 2.4. *Perceived hand volume*

The task to estimate hand volume was similar to the task of estimating hand weight. As shown in Fig. 1A & B, the participant had their left hand placed on a set of cushions and occluded from their view, and their right arm rested on their lap, under a cloak, also occluded from their view. In each trial, the experimenter placed a wooden cube on a table positioned in front of the participant (Fig. 1B), using a grabber to prevent the participant from viewing the experimenter's hand before making the estimation. The participant was asked to estimate if the cube was bigger or smaller than the felt volume of their left hand. They responded by saying ‘bigger’ or ‘smaller’. Participants were not given specific instructions on how to compare their hand's volume to the wooden cubes, to ensure that volume estimations reflected natural perception without predefined strategies. We chose cubes, rather than hand-shaped objects, to measure perceived volume in a way that isolates it from specific representations of hand size or shape and to prevent participants from relying on memory-based matching. The volumes of the 16 wooden cubes were logarithmically spaced between 190.92 and 624.88 cc, rounded to the nearest cubic centimeter. The volumes of the available stimuli were (in cc): 191, 214, 247, 275, 297, 320, 342, 368, 395, 422, 439, 452, 495, 534, 583, 625.

For hand volume, we used the average hand volume from the same study (Kaye & Konz, 1986) of 375.65 cc, averaged across dominant and non-dominant hands, and the staircase started with either 207.65 more (i.e., 583.30 cc) or 184.73 less (i.e., 190.92 cc) than the average.

On each trial, QUEST suggested which of the available stimuli to present based on Bayesian analyses of the responses on the previous trials together with the initial estimate. The two staircases alternated across trials, in each block. Though the two staircases started with different prior estimates of hand volume, they quickly converged on a common estimate of perceived hand volume (as shown in Fig. 1C).

### 2.5. *Actual hand volume and hand weight*

At the end of the experiment, measures of hand volume were collected using the water displacement method, as described in Ferrè et al. (2023). A container filled with water was placed on a digital scale (AMPUT APTP457A 7500 g, Shenzhen Amput Electronic Technology Co. Ltd) and tared to zero. The participant then submerged their left hand (up to, but not including the ulnar styloid process) into the water, ensuring that the hand did not touch the container itself. By Archimedes' principle, the weight applied to the scale is equal to the weight of water displaced by the hand (Bell, 1937). Because the hand was suspended and not resting on the container, the scale recorded only the increase in weight due to the displaced water, which directly corresponded to hand volume (since 1 g of water = 1 $cm^3$). Three successive measures of hand volume were collected and averaged. To calculate hand weight, the hand volume values were converted to an estimate of hand weight using the estimate of hand density (1.09 g/cc) reported by Kaye and Konz (1986). This density value is based on body composition assumptions (Clauser et al., 1969) and is supported by cadaver measurements estimating hand density at 1.07 $g/cm^3$ (Dempster & Gaughran, 1967). We used the same estimation of hand density for all participants, although there may be minor variability due to differences in muscle mass, adiposity, and bone structure. On average, participants' hands weighed 351.1 g (SD: 74.9 g), and had an average volume of 322.2 cc (SD: 68.7 cc). Finally, we collected measures of overall body weight using a standard commercial scale, and body height using a measuring tape. Participants on average weighed 68.1 kg (SD: 15.0 kg), and had an average height of 166.3 cm (SD: 9.8 cm).

## 3. Results

A psychophysical staircase procedure was used to estimate perceived hand weight and perceived hand volume. The results are shown in Fig. 1.

There was clear convergence between the high and low weight staircases, which were strongly correlated, $r(28) = .97$, $p < .0001$, showing high reliability of hand weight estimates. For individual staircases of perceived hand weight and volume, see Supplemental Figure S1. We calculated a percentage of overestimation with the formula: 100*(perceived weight − actual weight)/actual weight. The value obtained is a ratio of perceived weight to actual weight, and when we obtain a negative value, it means the perceived weight is less than the actual value, when it is positive, it means it is more than the actual value. We then conducted a one-sample *t*-test against 0 to assess whether there was a significant overestimation or

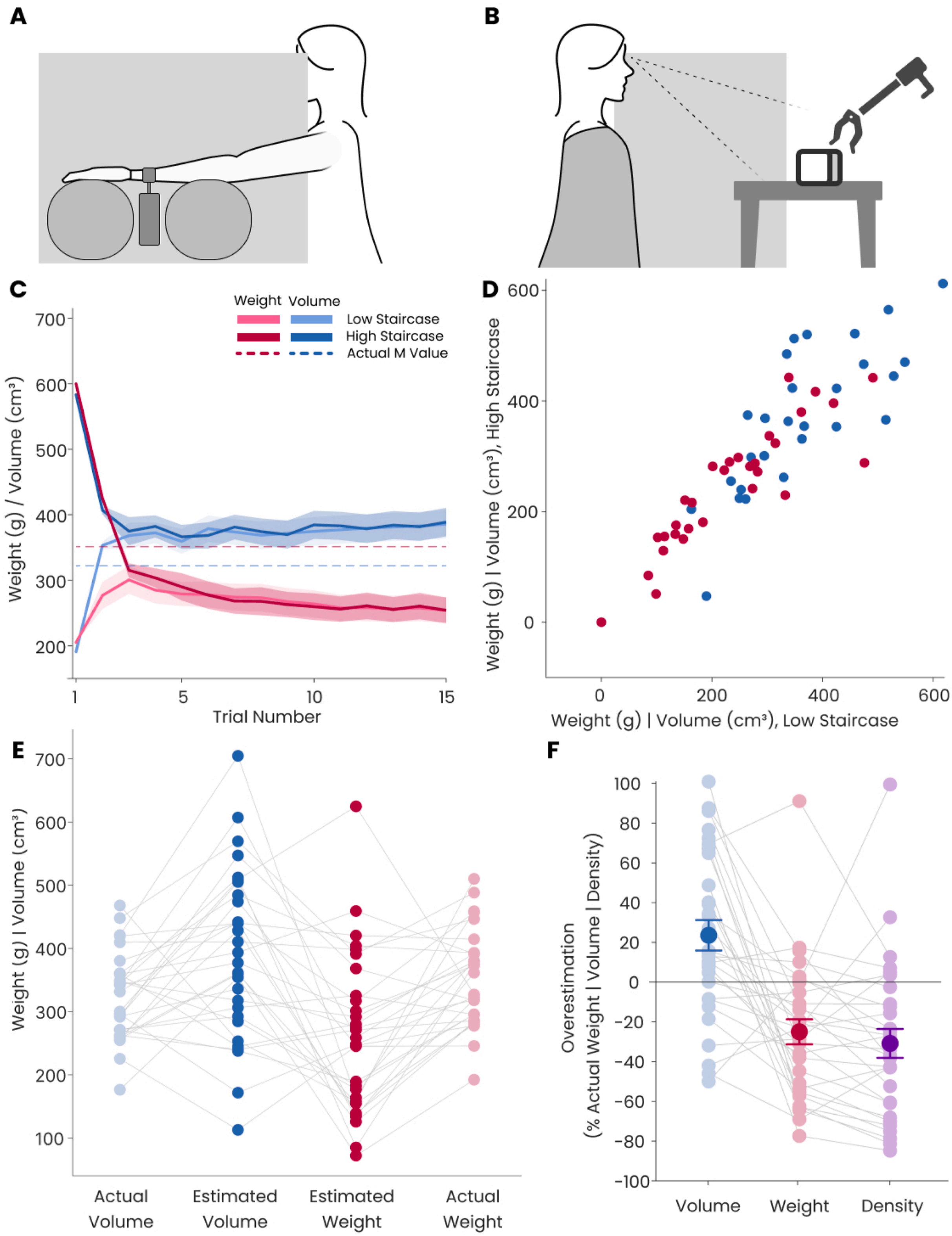


Fig. 1 — A. Setup for the hand weight task. The participant had their left hand rest between two pillows, while wearing a wristband to which the weights were hung in each trial. At the beginning of each block, the participant hung their hand to feel its weight. B. Setup for the hand volume task. In this task, participants viewed a block, which was placed in a table using a grabber. In both tasks, the hands were occluded from the view. C. The low and high staircases converged on common estimates of perceived hand weight and hand volume. The dashed horizontal lines indicate the actual hand's mean weight and mean volume. The light lines represent individual staircases. D. Estimates of hand weight and hand volume were strongly correlated between the two staircases for both properties, $p < .001$. E. Participants estimated the

underestimation of perceived hand weight to actual hand weight. We replicated the systematic hand weight underestimation, with an average underestimation of hand weight of −25.0% of actual hand weight, $t(29) = 3.97$, $p < .001$, $d = .725$.

For volume, we calculated a percentage of overestimation with the formula: 100*(perceived volume − actual volume)/actual volume. The value obtained is a ratio of perceived volume to actual volume. We then conducted a one-sample t-test against 0 to assess whether there was a significant overestimation or underestimation of perceived hand volume to actual hand volume. Positive values indicate overestimation, while negative values indicate underestimation. The term *percentage overestimation* refers to this signed estimation error metric, which expresses the deviation from the actual value as a proportion, in a one-dimensional continuum. There was clear convergence between the high and low volume staircases, which were strongly correlated, $r(28) = .99$, $p < .0001$, showing high reliability of hand volume estimates. There was an average overestimation of hand volume of 23.6% of actual hand weight, $t(29) = 3.08$, $p = .004$, $d = .563$.

Hand weight overestimation did not correlate with hand volume overestimation, $r(28) = -.003$, $p = .988$. Hand weight estimates also did not correlate with hand volume estimates, $r(28) = .167$, $p = .378$.

Having measured perceived hand weight and perceived hand volume, we were able to obtain a value of perceived hand density, per participant, in the same way that density is defined by mass divided by volume. We calculated perceived hand density using a ratio of perceived weight in grams to perceived hand volume in cm. The perceived hand density is calculated as a ratio of perceived weight to perceived volume, meaning its underestimation reflects the combined effect of these two estimations, rather than a simple addition of their individual percentage errors. We calculated a percentage of overestimation with the formula: 100*(perceived density − actual density)/actual density. The value obtained is a ratio of perceived density to actual density (1.09 g/cm$^3$), for each participant. We then conducted a one-sample *t*-test on the mean percentage error against 0 where 0 represents no difference between perceived and actual density. A significant result would indicate a systematic overestimation or underestimation of hand density. The mean perceived hand density was .75 g/cc (SD: .08). We found a clear average underestimation of hand density of −30.8% of actual hand density, relative to the hand density of 1.09 g/cc estimated by Kaye and Konz (1986), $t(29) = 4.25$, $p < .0001$, $d = .776$.

## 4. Discussion

Here we demonstrated that the perceived volume of our hand is overestimated, on average by 24% compared to its actual size. This means we perceive the entire hand as larger than it is, not just in terms of its external dimensions, but also regarding the perceived internal space. That is, we perceive our hand as occupying more space in 3D than it truly does. We replicated the underestimation of hand weight we recently reported (Cadete et al., 2025; Ferrè et al., 2023), with participants perceiving their hand on average as 25% lighter than its actual weight. When we perceive our hand both as more voluminous and lighter than it actually is, the resulting perception of hand density is also distorted. Based on estimates of hand volume and weight, we calculated perceived hand density, using perceived hand weight divided by perceived hand volume. We found that hand density was underestimated on average by −31%. We feel that our hand is way less dense than what it actually is, as if the hand was made of lighter materials that take up more space than the true weight of bones, muscles, tendons, fat and blood. This means that our hand is perceived to have the same density of a sponge or foam, with a low density of .8 g/cc. It also means that our hand would float in water. Volume of the hand is overestimated, its weight underestimated, and therefore, its density is also underestimated. Establishing how these three physical properties of the hand are mentally represented in their natural state is important to investigate how they dynamically interact in the representation of our own body parts, and how they differ in clinical conditions.

Before this study, the finding that we systematically underestimate the weight of our hand (Ferrè et al., 2023) could be interpreted as simply reflecting an underestimation of hand size: if the hand is perceived as smaller than it really is, its weight might be underestimated accordingly. This study shows that this is not the case. Healthy humans systematically perceive their hand to have a larger volume than it actually has. Hence, the perceived weight of the hand is not a perceptual product of underestimating its volume, since volume is actually overestimated. In the constant density model (Cadete et al., 2025), changes to the perceived size of the hand are computed along with perceived weight, maintaining perceived density constant. So, when the hand feels bigger, it feels heavier, as the hand density is maintained the same, resulting in the perception of having more of the same 'stuff' that the hand is felt to be made of. Likewise, when we perceive to have a smaller hand, we feel the hand is lighter, because there is less 'hand material'. In that study, the participant saw the reflection of their hand enlarged, normal or shrunken in a magnifying, normal or minifying mirror, while feeling and seeing brush strokes on the hand to enhance the illusion. The visual-tactile stimulation provided information about the hand volume, as the hand was seen through the mirror, so it can be described as a change in hand volume and not solely as surface hand size. We can then infer that the change to hand volume then produced the change in perceived weight. Perceived weight increases as a function of increased hand size, keeping density as a stable representation for that body part. The results of the present study show that the baseline for perceived hand volume is larger than it actually is, and perceived hand density lower than it is. Perceived hand weight is also lower than its actual weight, a finding

**volume of their hand to be higher than it actually is, and the hand weight to be lower than it is. F. There was an overestimation of hand volume, and underestimation of hand weight. Estimated hand density, calculated from perceived hand volume and hand weight, was underestimated. Error bars are one standard error.**

consistent with previous studies (Cadete et al., 2025; Ferrè et al., 2023). Until this study, it was unclear whether the hand weight underestimation was a product of a distorted representation of hand size, in either direction. Our results, however, show that hand weight underestimation did not correlate with hand volume overestimation. This indicates that both estimations are independent at baseline.

The hand is one of the body parts we most frequently use to interact with the world, and has the highest surface area to its volume. Because of this, the hand was expected to be less underestimated in volume, as described in Sadibolova et al. (2019). However, more than a lesser underestimation, we found a mean overestimation of hand volume by 24% relative to its actual volume. Considering that hand width is overestimated by 60–80%, even with the 20–30% of underestimation of the size of the fingers, an overall volume overestimation is unsurprising. At the same time, Sadibolova et al. (2019) showed that body parts that are overestimated in size, tended to be underestimated in volume, highlighting a pattern in how we represent the volume of body parts. Our findings suggest that the hand representation may stretch that pattern further: instead of being merely less underestimated in volume, the hand volume is actually overestimated, possibly due to the hand's unique role in interacting with the environment and tools.

Understanding how dense we perceive our hand in everyday life is crucial because weight perception does not exist in isolation, it is inherently tied to the volume of the hand. The weight of a body part is not a pure measurement, but rather a property that is constrained by its physical limits, described as volume. Together, these two physical attributes are integrated into the perceived density of the hand, reflecting how much weight is distributed within a given space. As we have previously argued (Ferrè et al., 2023), perceiving the hand as lighter than it actually is can be advantageous for movement. A hand that feels light facilitates motor execution, allowing actions to be performed effortlessly. As fatigue sets in, there is a reduction of this hand weight underestimation, to promote rest (Ferrè et al., 2023). However, because perceived weight is not independent from perceived volume, a low-density hand may actually be the perceptual goal of this systematic distortion. If the hand is felt as lighter than it actually is, while also being perceived as more (or as) voluminous, then a lower perceived density would naturally follow. This suggests that the consistent underestimation of hand density is not an error but a functionally adaptive property of body representation. A low-density hand may optimise motor performance by reducing the perceived energetic cost of movement, sustaining fluid actions until fatigue triggers a recalibration. This perspective helps explain why these perceptual distortions do not interfere with everyday interactions with objects and people, instead, they may be essential for maintaining an optimal state for action control. A second hypothesis is that perceived hand volume and perceived hand weight are distorted independently, each offering separate advantages, with the resulting low density being a byproduct rather than an intended feature of body representation.

As a third hypothesis, we propose that perceived density is the key property the brain maintains constant, rather than weight or volume independently. This builds on the constant hand density model, which suggests that when the perceived size of the hand changes, the perceived weight updates accordingly to maintain a stable density representation (Cadete et al., 2025). If this principle extends to the baseline body representation of hand density, then perceived weight and volume may not be freely distorted but rather dynamically adjusted to sustain a functionally advantageous perception of density. This would mean that density is not just a byproduct of two separate distortions but a reference point in body representation, with weight and volume calibrating around it. Such a mechanism could explain why perceived weight and volume do not correlate in our data, as they are not independently estimated but instead constrained by the need to preserve a stable, low-density representation of the hand.

In this study, we have now shown the baseline for perceived hand volume and perceived hand density. Our brain maintains the hand density constant, yet, the baseline seems to be greatly underestimated, as if the human hand was made of foam (.8 g/cc) and not made of blood, bones, tendons and tissues that together make the hand's actual density of 1.09 g/cc.

If we exhibit such distortions in our perception of weight, volume and density of the hand, it may seem surprising that it does not compromise everyday interactions with objects and people. However, we argue that rather than being a limitation, these distortions enable efficient and accurate motor control. One reason these perceptual distortions do not lead to movement errors is that underestimating hand weight enhances weight discrimination (Ferrè et al., 2023). If the human brain included the full weight of the hand in object weight judgments, the contrast between objects would be reduced, making discrimination harder. By perceptually subtracting the hand's weight, the brain resets the reference point, allowing for finer weight judgments and better force application, as argued elsewhere (Ferrè et al., 2023). However, weight perception does not exist in isolation, it is always tied to perceived volume, and together, these two properties define perceived density. A lower perceived density ensures that the hand feels lighter, which enhances weight discrimination and optimises force application in interactions with objects. A similar principle exists in robotic movement optimisation, where reducing or isolating the robot's own weight is essential for efficient motion. Robotic systems use gravity compensation mechanisms, such as counterweights, auxiliary actuators, and spring-based balancing to isolate the effects of the robot's mass and improve force control (Arakelian, 2016; Ulrich & Kumar, 1991, pp. 1536–1541; Yun et al., 2019, pp. 3565–3570). Without these mechanisms, robotic limbs would require significantly more energy to move, and control precision would be reduced. Robots must be explicitly programmed to compensate for their weight, while humans, as our research suggests, have a default underestimation of hand weight and hand density, with low-density perception possibly being a functional property of body representation. This principle is also observed in rehabilitation robotics, where compensating for the weight of a person's arm allows for more fluid movement control during motor recovery. Just et al. (2020) discuss how exoskeletons and robotic assistive devices compensate for arm weight to facilitate movement without disrupting natural motor coordination. This provides further evidence that weight compensation is crucial for smooth motor control. Future research can explore whether low-density perception optimises motor efficiency.

Research on prosthesis use in amputees further supports this point. Amputees often reject prosthetic limbs because they feel too heavy, even when the prostheses weigh less than biological limbs (Belter & Dollar, 2011; Pylatiuk et al., 2007; Sinha et al., 2014; Turner et al., 2022). This suggests that if we perceived the full weight of our own limbs, everyday actions would feel effortful and unpleasant. Recent work shows that when artificial sensory feedback is added to prosthetic limbs, the perceived weight of the prosthesis is reduced by up to 23%, with improvements in walking performance and limb embodiment (Preatoni et al., 2021). This suggests that a reduced perception of weight and density is both a fundamental aspect of embodiment and for ensuring that actions do not feel intensely effortful.

Our study has the limitation that perceived hand density was calculated indirectly, by dividing perceived hand weight by perceived hand volume. It is not necessarily the case that the density of the hand is perceived as a precise reflection of how much weight is perceived to occupy a defined volumetric space. At the same time, measuring directly perceived hand density introduces challenges, due to the size–weight illusion, which distorts perceived object weight when volume and weight are experienced simultaneously (Buckingham, 2014; Charpentier, 1891). This is particularly problematic given the different ways in which the brain processes bodily weight and object weight (Cadete et al., 2025). To isolate the contributions of each property, we designed the experiment so that hand weight and volume were estimated separately, without visual input during weight judgments and tactile input during volume judgments, preventing the effect of perceived volume on perceived weight, and, conversely, the effect of perceived weight on perceived volume. In physics, density can be directly computed as mass divided by volume, however, it is still unclear how volume, weight and density interact in the perception of parts of our body. This study contributes to this understanding by presenting a baseline overestimation of hand volume, while replicating a baseline underestimation of hand weight, and an indirect calculation for a baseline underestimation of hand density.

## CRediT authorship contribution statement

**Denise Cadete:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Pearl Young:** Methodology, Investigation, Formal analysis. **Brad Hallett:** Resources, Methodology, Investigation. **Elisa R. Ferrè:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Matthew R. Longo:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

## Scientific transparency statement

DATA: All raw and processed data supporting this research are publicly available: https://osf.io/psfu5.

CODE: This research did not make use of any analysis code.

MATERIALS: All study materials supporting this research are publicly available: https://osf.io/psfu5/

DESIGN: This article reports, for all studies, how the author (s) determined all sample sizes, all data exclusions, all data inclusion and exclusion criteria, and whether inclusion and exclusion criteria were established prior to data analysis.

PRE-REGISTRATION: No part of the study procedures was pre-registered in a time-stamped, institutional registry prior to the research being conducted. No part of the analysis plans was pre-registered in a time-stamped, institutional registry prior to the research being conducted.

For full details, see the *Scientific Transparency Report* in the supplementary data to the online version of this article.

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## Supplementary data

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