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Head – body ratio as a visual cue for stature in people and sculptural art

George Mather
School of Psychology, University of Sussex, Falmer, Brighton BN1 9QH, UK;
e-mail: g.mather@sussex.ac.uk
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Abstract. Body size is crucial for determining the outcome of competition for resources and mates. Many species use acoustic cues to measure caller body size. Vision is the pre-eminent sense for humans, but visual depth cues are of limited utility in judgments of absolute body size. The reliability of internal body proportion as a potential cue to stature was assessed with a large sample of anthropometric data, and the ratio of head height to body height (HBR) was found to be highly correlated with stature. A psychophysical experiment was carried out to investigate whether the cue actually influences stature judgments. Participants were shown pairs of photographs of human figures in which HBR had been manipulated systematically, and asked to select the figure that appeared taller. Results showed that figures with a relatively small HBR were consistently perceived as taller than figures with a relatively large HBR. Many classical statues such as Michelangelo's *David* depart from the classical proportions defined in Leonardo's *Vitruvian Man*. A supplementary experiment showed that perceived stature in classical statues also depends on HBR. Michelangelo's *David* was created with the HBR of a man 165 cm (5 ft 5 in) tall.

1 Introduction

In many species, body size is a key factor in determining the outcome of competition for resources and for mates (Owings and Morton 1998). Acoustic signals are used as an index of caller body size by species such as deer and dogs (Reby and McComb 2003; Charlton et al 2007; Taylor et al 2009). Research on sexual behaviour demonstrates that stature matters even in human behaviour (Mueller and Mazur 2001), but very little is known about how humans judge stature. The visual sense is pre-eminent in humans but most visual cues to depth and size, such as binocular disparity, provide information only about the relative size of objects, not about their absolute size. Even the cues which do offer absolute size information (binocular convergence and accommodation) are of limited utility beyond a range of about 3 m (Mather 2009). Here I investigate a potential cue to human stature that does not rely on conventional visual depth cues. If the relative size of different body parts varied consistently with stature, then body proportion would offer a visual cue to body size that would allow humans to dispense with the need to rely on depth cues. Kato and Higashiyama (1998) asked subjects to give verbal estimates of stature in photographic images of people (in inches or centimetres), and then correlated estimates against several body proportions. They found that the ratio of head height to body height, head – body ratio (HBR), accounted for the greatest proportion of variance in the data. However, there were two limitations in this study. First, it offered no normative data to establish the ecological validity of the HBR cue. Second, it did not evaluate the proposal by manipulating the HBR cue experimentally and testing for consequent variations in stature judgments. In the present study I therefore report normative anthropometric data on HBR, and the results of an experiment that manipulated the HBR cue. In a second experiment I tested the effectiveness of the cue in classical statues.

Two large anthropometric databases (Hertzberg et al 1963; Grunhofer and Kroh 1975) include measures of 150 body parts in 4789 German and NATO (Italian, Greek, and Turkish) male military personnel (unfortunately, the databases do not include data on female personnel). To compare potential visual cues to stature, four of the most visually salient body proportions were derived from the data—head height, crotch height, shoulder width, and palm width—all expressed as a proportion of stature. Figure 1 shows the correlation of each proportion with stature, with 95% confidence intervals. HBR offers the most reliable cue to stature. Note that, even if there were no systematic relation between body proportion and stature, the correlations in figure 1 would still be expected to exceed zero. Monte Carlo simulations showed that if we take two independent random variables x and y, and calculate the correlation of x with the ratio $x : y$, then the expected correlation is 0.11, shown by the dashed horizontal line in figure 1. The correlation of HBR with stature is significantly higher than this chance level. Although, in absolute terms, taller men have larger heads, relative to their total height their head tends to be rather small.

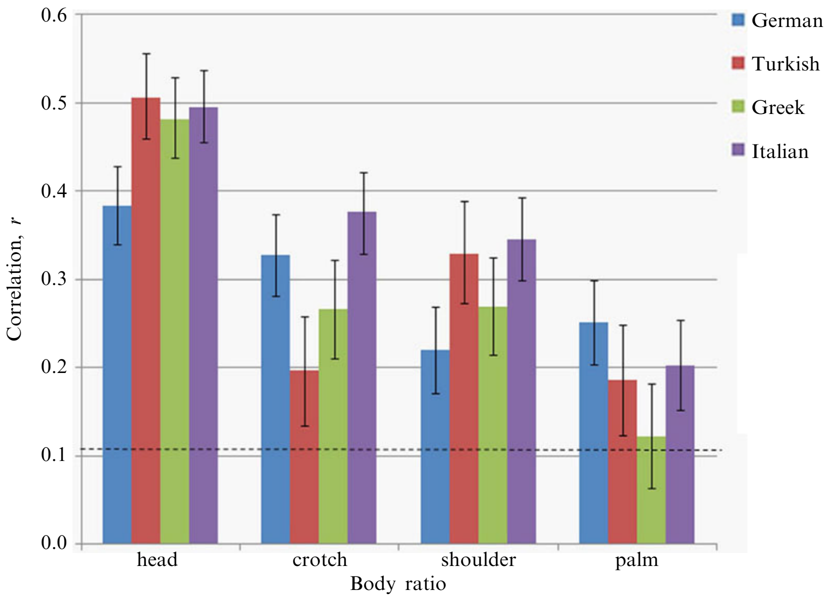

Figure 1. [In colour online, see http://dx.doi.org/10.1068/p6737] Correlation of four body proportions with stature in large samples of male military personnel. The columns show the absolute value of r (all correlations except crotch height were negative). Vertical bars show 95% confidence limits. The dashed horizontal line shows the correlation expected by chance (derived from Monte Carlo simulations).

The mean HBR across the entire anthropometric dataset was 0.13 (SD = 0.0073; range 0.097 – 0.153). Interestingly there were slight differences between the German dataset and the NATO dataset (Turkish, Greek, and Italian). In particular, mean HBR for the German personnel was 0.125 and mean stature was 1769 mm. The NATO dataset showed a slightly larger mean HBR at 0.132, and a shorter stature, at 1701 mm.

Having established that an honest (though less than perfect) visual cue to body size is available, I conducted a psychophysical experiment to assess whether visual judgments of stature are actually influenced by manipulation of HBR.

2 Methods

2.1 *Subjects*

Ten naive observers participated in the experiment.

2.2 *Materials and apparatus*

Full-figure frontal digital photographic images of four clothed males were manipulated to create three versions of each figure, depicting HBRs of 0.11, 0.13, and 0.15, which span the range found in the anthropometric data (examples are shown in figure 2). Body size in the image was kept constant.

Photographs were presented in pairs on a CRT monitor (Sony Trinitron, 1260×780 pixels) against a mean luminance grey background (26 cd m^{-2}). Body height in all images subtended 16 deg at the 57 cm viewing distance. Centre-to-centre horizontal separation of each pair of images was 20 deg. The vertical position of each image varied randomly from trial to trial over a range of ± 2 deg. The experiment was controlled by an Actionscript program running on a Windows PC.

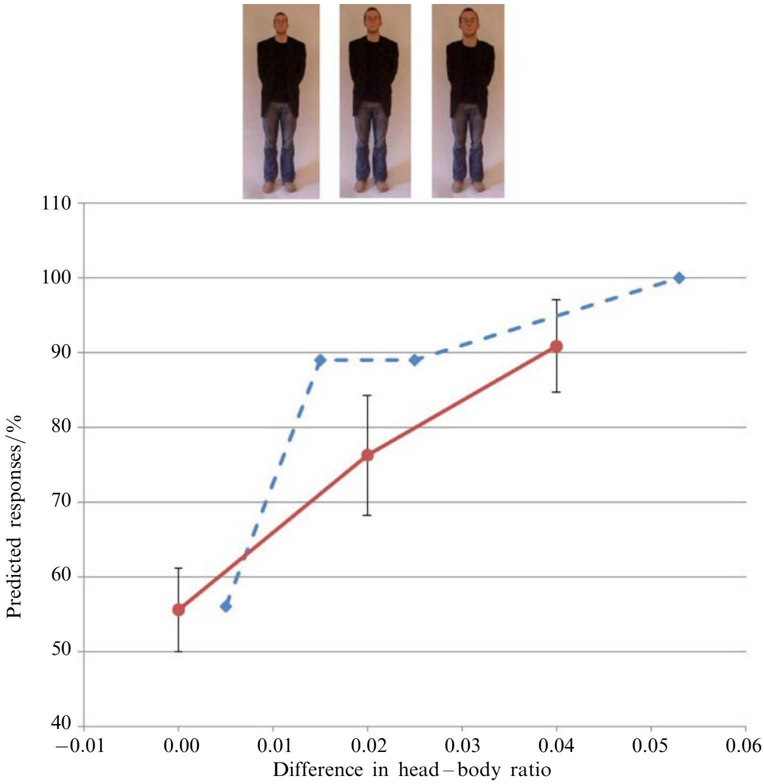

Figure 2. [In colour online] Results of two experiments on stature judgment in pairs of photographs differing in HBR. Results are plotted as percentage of responses predicted by HBR as a function of the difference in HBR. Solid line: results from ten naive observers viewing photographs of male figures. Vertical bars represent 95% confidence limits. Broken line: results from eighteen naive observers viewing photographs of classical statues. The small photographs show example stimuli with HBR of 0.11, 0.13, and 0.15.

2.3 *Procedure*

There were 54 possible pairings of the nine photographs, given the constraint that two different images of the same individual were never presented together, making 54 trials in total which were presented in random order to each participant. In each trial the pair of images was presented side-by-side, and the participant was instructed as follows: "Which person looks taller? Ignore size on the screen". The participants indicated their responses by pressing one of two response keys. Images remained visible until a response was made, and a uniform grey inter-trial interval of 0.5 s separated successive trials.

3 Results

During debriefing, the participants were asked whether they noticed anything in particular about the photographs, and none indicated that he had been aware of the head-size manipulation. For image pairs containing a difference in HBR, each response was scored according to the prediction that the figure with the smaller HBR would be perceived as taller. For image pairs with equal HBR, responses were scored according to the actual stature of the individual depicted (measured at the time the image was recorded). If other cues influence stature judgment, then responses should be consistently correct even when there is no difference in HBR.

Solid lines in figure 2 show the mean percentage of responses in the predicted direction for each difference in HBR. Vertical bars show 95% confidence limits. Stature judgments depend lawfully on the difference in HBR between the two figures; at the larger difference, 90% of responses are in the direction predicted by HBR. A one-factor analysis of variance confirmed that the effect of HBR was highly significant ($F_{2} = 55.7, 18, p < 0.0001$).

4 Discussion

The experiment provides convincing evidence that body proportion is used as a lawful visual cue for the judgment of human body size: manipulations of HBR influence judgments of stature. Responses are close to chance when there is no difference in HBR, indicating that any other cues in the images (eg other body proportions or image perspective produced by different actual heights) are ineffective.

At first sight, this result seems at odds with the classical canon of human body proportions. Leonardo's *Vitruvian Man* depicts a classically proportioned human figure with an HBR of 1/8 or 0.125 (Panofsky 1955a). Many classical statues from Greece and Italy conform to this ideal, but some do not. Michelangelo's *David* (Accademia, Florence), and statues of David by Donatello and by Verrocchio, have an HBR of over 0.14, while the Roman bronze *Hercules* (Capitoline Museum, Rome), and other statues of Hercules, have an HBR of 0.11 or less. Some art historians have suggested that the relatively large head of Michelangelo's *David* was an attempt by the artist to compensate for the low position from which the statue is normally viewed (Seymour 1967), though there is no documented evidence to support this suggestion. Another possible explanation for this and other departures from classical proportion is that sculptors exploited the HBR cue (either consciously or unconsciously) and varied body proportion to convey the stature of their subjects.

To test this idea, and to assess the generality of the HBR cue, a supplementary experiment was carried out to test whether perceived stature in classical statuary is influenced by HBR. With an identical procedure to the previous experiment, eighteen naive observers were each shown four pairs of photographs depicting classical statues with different HBR and asked: "If these statues were real people, who would be taller?" The pairs used were:

Donatello's *David* (HBR 0.157) versus the Capitoline *Hercules* (HBR 0.104)

Verrocchio's *David* (HBR 0.157) versus Bandinelli's *Hercules and Cicus* (HBR 0.132)

Michelangelo's *David* (HBR 0.143) versus Michelangelo's *Victory* (HBR 0.138)

Riace Warrior B (HBR 0.125) versus *Riace Warrior A* (modified HBR 0.14)

Three of the pairs include statues of David by three Renaissance sculptors. In all three cases the artist may have used HBR to depict the small, youthful stature of the mythical figure. As a test for other cues, the fourth pair of photographs depicted the ancient Greek Riace Warriors, which actually have the same classical HBR (0.125) and are thought to have been produced from the same model (they were found together near the Italian coast in 1972; see Stewart 1990). For the experiment, the photograph of one of the statues (known as *Riace A*) was manipulated digitally so that its head size was increased to give an HBR of 0.14. If HBR alone can influence stature judgment, then this manipulated statue should be judged as smaller in stature than the other warrior (*Riace B*) even though there are no other differences in proportion between the two statues. The broken line in figure 2 shows the data for the second experiment, which confirms that stature judgments in classical statuary are also governed by HBR. On aggregate, the eighteen subjects selected the statue with the smaller HBR as 'taller' in 83% of their responses (60/72 trials). For the Riace Warriors in which HBR was the only cue to stature, 89% of subjects selected the statue with the smaller HBR as 'taller'.

Linear regression on the anthropometric data produces an equation that can be used to predict stature from HBR. When this calculation is applied to Michelangelo's *David*, the statue is calculated to represent a figure standing at 165 cm or about 5 ft 5 in, while the Roman statue *Hercules* in the Capitoline Museum, Rome, would stand 186 cm or 6 ft 1 in tall. Figure 3 contains sketches of these two statues, along with a *Riace Warrior*, scaled to match relative stature as calculated from HBR. These heights bear no relation to the actual heights of the statues themselves; *David* stands at 4.09 m (Olson 1992); the *Riace Warrior* stands at 2.0 m (Pacini 1981); the Capitoline *Hercules* stands at 2.41 m (Haskell and Penny 1981).

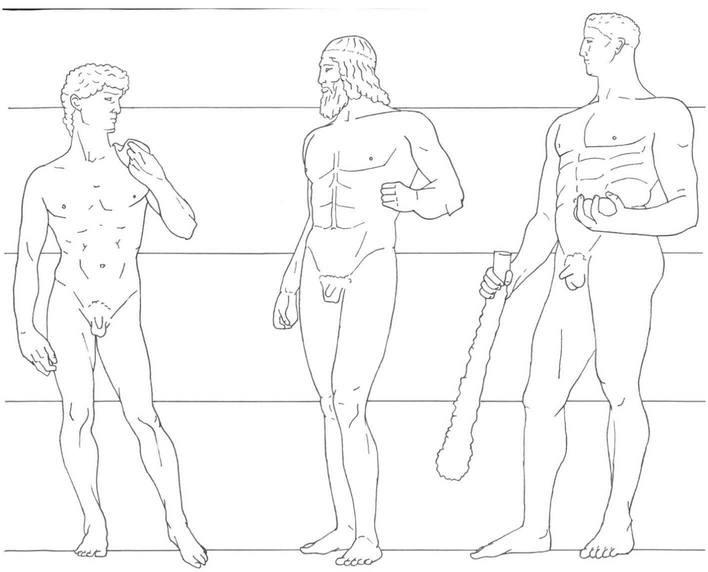

Figure 3. Three statues (Michelangelo's *David*, *Riace Warrior A*, Capitoline *Hercules*), drawn to scale so that their relative heights reflect the relation between HBR and stature calculated from the normative data. The horizontal lines are drawn at heights of 0, 50, 100, and 150 cm. Note that this scale drawing bears no relation to the actual heights of the statues (*David* stands at 4.09 m; the *Riace Warrior* stands at 2.0 m; the Capitoline *Hercules* stands at 2.41 m).

A note of caution is required, because the calculations used for figure 3 assume that the proportions and heights of modern populations are applicable to humans who lived hundreds or thousands of years ago. This assumption is impossible to verify, of course (standard units of linear measurement were introduced only within the last 200 years). Morant (1950) analysed trends in adult stature over a 100-year period between 1850 and 1950, on the basis of records of over two million British men, and found very little change in stature. On the other hand, there is evidence that stature can change over periods spanning tens of thousands of years (Hermanussen 2003).

The canonical 1/8 HBR embodied in *Vitruvian Man* (0.125) is near the middle of the range of HBRs calculated from the anthropometric dataset (in fact exactly on the average HBR of the German dataset, and slightly smaller than the mean HBR of the NATO dataset). 400 years ago the artist Albrecht Dürer studied proportion empirically, and argued that the classically proportioned figure represents a middle ground ('happy medium', in Panofsky's 1955b translation) between the more extreme proportions which he described as "coarse and rustic" or "long and thin" (Dürer 1970). Dürer argued that 'average' proportions were more aesthetically pleasing. A similar argument can be found in the modern literature on facial beauty. The most beautiful faces tend to be the most average faces, in statistical terms (Rhodes 2006). There may be an evolutionary basis to an aesthetic preference for average proportions since it reflects optimum functioning and development, or evolutionary 'fitness' (Rhodes et al 2001).

In summary, human body proportion offers an honest cue to body size, and two perceptual experiments provide evidence that human judgments of stature, both in real human figures and in statues, is influenced by head-to-body ratio.

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