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‘At risk’ waist-to-height ratio cut-off points recently adopted by NICE and US Department of Defense will unfairly penalize shorter adults. What is the solution?

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ABSTRACT

Objectives: To a) demonstrate that adopting ‘at risk’ waist-to-height ratio (WHTR) cut-off points, recently approved by National Institute for Health and Care Excellence (NICE) and the United States Department of Defense (USDoD), will unfairly penalize shorter individuals and will be too lenient for taller individuals, b) to confirm that waist circumference (WC) of a sample of US service personnel, scales to approximately height$^{0.5}$, supporting the notion that WC, to be independent of height (HT), should be normalized using WC.HT$^{-0.5}$ (WHT•5R), and c) to identify the WHT•5R cut-off points that will reduce or eliminate this unwanted bias.
Subjects/methods: We employed a three independent cross-sectional sample design. All n = 58,742 participants underwent anthropometric assessment of body mass, stature and waist circumference.
Results: The allometric power-law model WC=a.HT^b for US service personnel identified the height exponent to be b= 0.418 (95 % CI 0.251–0.585), confirming that the simple body-shape index for WC to be independent of HT, should be WC.HT$^{-0.5}$. Chi-square tests of independence and for linear trend confirmed that by adopting WHTR cut-off point, shorter individuals (both service personnel and non-service participants) will be over penalized (classified as being ‘at risk’). New WC independent-of-height ratio cut-off points were found to resolve this problem.
Conclusions: Adopting WHTR cut-off thresholds (either 0.5 or 0.55) will lead to shorter adults being unfairly classified as being ‘at risk’ in terms of their central adiposity and general health status. Adopting new WHT•5R cut-off point thresholds were found to greatly reduce or eliminate this bias.

Introduction

Numerous studies now recognise the importance of waist circumference (WC) as a more sensitive anthropometric measure associated with obesity and health risk compared with, for example, BMI [1-6]. This importance of WC related indices, over BMI, has most recently been supported by research in children [7] in adults with Type 2 Diabetes [8], and for monitoring cardiometabolic multi morbidity in national cohort studies [9]. WC is also an important indicator of aerobic fitness [10]. However, taller individuals naturally have a larger WC than shorter individuals but are not necessarily either less fit or at greater health risk. For this reason, researchers have explored ways to scale or normalise

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WC to remove this association with height. To this end, Ashwell et al. [1] proposed a simple waist-by-height ratio (WHTR) thought to overcome this unwanted and potentially misleading association. This research appears to have been the catalyst for a) the United States of America's Department of Defense (USDoD)'s decision to adopt waist-to-height ratio (WHTR<0.55) as one screening procedure for identifying acceptable/unacceptable body composition for service personnel, and b) NICE's decision to recommend 'Keep the size of your waist to less than half of your height' (or WHTR<0.5) in their latest draft guidelines to assess and predict health risks, such as type 2 diabetes, hypertension or cardiovascular disease [11].

Indeed, the USDoD cleared for public release (March 10, 2022) revised procedures for their 'Physical Fitness and Body Fat Programs' [12]. In this report, they announced the adoption of a new WHTR as part of their body composition evaluation procedures. The rationale for replacing unadjusted WC was 'Service determination of body composition relying on abdominal or WC will use evidence-based reference indexes corrected for height that is not biased against short or tall service members'. However, the USDoD's and NICE's assumption that the WHTR is unbiased, and that adopting the simple WHTR ratio cut-off point (WHTR<0.5) will overcome this unwanted and potentially misleading association, is incorrect.

The belief that WHTR is a better proxy measure of adiposity, and NICE's subsequent guidelines advocating 'Keep the size of your waist to less than half of your height' (or WHTR<0.5) over other methods of assessing weight-related health, has been questioned [13]. Nevill, et al. [13] demonstrate that unadjusted WC penalizes taller individuals and go on to show that NICE's new cut-points for 'at risk' based on WHTR< 0.5 are also biased in the opposite direction. NICE's new guidelines unfairly penalize shorter rather than taller individuals and are overly lenient in classifying risk for taller individuals. This is a significant shortcoming of the NICE guidelines which are designed to support public-health decisions related to obesity and weight-related health.

The solution is simple, and was hinted at by Nevill et al. [13], but requires explanation. Nevill et al. [4] identified a more precise method of normalizing or scaling WC for differences in height, showing that their new ratio, waist divided by height$^{0.5}$ (WHT•5R), is not only independent of height (using allometric scaling) but also a stronger predictor of cardio-metabolic risk (CMR) compared with a wide range of other anthropometric indices. Likely explanations are twofold. First, WC is likely the most sensitive dimension to detect changes in adiposity, certainly better than BMI, which reflects changes in muscle mass and adiposity. Second, using height$^{0.5}$ to normalize or scale WC for individuals of different body size is more suitable — WHT•5R is both theoretically [14] and empirically [4] independent of height and also unaffected by changes in adiposity. Unadjusted WC penalizes taller individuals (i.e., taller people will have, on average, greater WC but not necessarily have any greater cardio-metabolic risk). In contrast, WHTR penalizes shorter individuals (the correlation between WHTR and height is negative, i.e., height over scales WC). The only WC-by-height ratio that will not penalize taller or shorter individuals (i.e., it removes the effect of height from WC completely) is WHT•5R=WC.Height$^{-0.5}$ [4] i.e., it correctly scales WC for differences in height.

Hence the purpose of the current study is; a) to confirm the WC of a sample of US service personnel also scales to approximately height$^{0.5}$, similar to the association identified by Nevill et al. [4] (using UK non-service participants), and b) to demonstrate that by adopting a criterion/cut-off point using either WHTR= 0.55 or 0.5, the USA DoD will more frequently penalize the shorter rather than the taller service personnel, a similar effect to that suggested by Nevill, Duncan and Myers [13], and c) to show adopting the waist-independent-of-height ratio (WHT•5R) cut-off points equivalent to WHTR = 0.55 and 0.5, the tendency to penalize shorter or taller people will be greatly reduced or eliminated.

Methods

Participants

Three independent samples were recruited. For sample 1 (US Service Personnel), investigators adhered to Department of Defense Instruction 3216.02 and Code of Federal Regulations (CFR) 32 219 [15] on the use of volunteers in research. The reporting of secondary research data (originally collected for a non-research purpose) is exempt from Institutional Review Board (IRB) review. For sample 2 (non-service UK participants), institutional ethics approval was obtained from the University of Essex with written informed consent obtained prior to any data collection. For sample 3, ethics approval was obtained by the Health Survey for England (HSE) from the Oxford A Research Ethics Committee, Oxford B Research Ethics Committee, West London Research Ethics Committee, and the East Midlands Nottingham 2 Research Ethics Committee.

- Sample 1 consisted of 589 adults (436 men, 153 women), aged 18–51 years (Mean age ± SD = 29.4 ± 6.6 years), of active-duty personnel stationed at a large United States air force base within the continental U.S. as part of a base-wide fitness testing and health promotion program. Such assessments do not meet the definition of protected health information as outlined in department of defense manual (DoDM) 6025.18, [16, page 46]. Inclusion criteria were U.S. active-duty air force personnel deployed within the continental U.S. Exclusion criteria were not meeting the inclusion criteria outlined above.
- Sample 2 consisted of 4763 adults (4117 males, 646 females), aged 20–69 years (Mean age ± SD = 48.6 ± 8.2 years) who attended one of five Health & Wellbeing clinics around England for a three-hour health assessment between 2000 and 2009 [5]. Inclusion criteria were being able-bodied, and aged 20–69 years with no musculoskeletal or cognitive impairment. Exclusion criteria were not meeting the inclusion criteria outlined above.
- Sample 3 consisted of a stratified random probability sample of 53390 participants (90 % Caucasian (n = 48135), 6 % South Asian (n = 3105), 1.6 % Black (n = 874), 1.8 % mixed ethnicity (n = 969), 0.6 % other ethnicity (n = 307)) from private households in England obtained from pooled data from ten years of HSE) 2008–2018 [16]. Inclusion criteria were all adults aged 16 years and over from each household sampled. Exclusion criteria were not meeting the inclusion criteria outlined above.

Procedures

The procedures used for data collection across samples were comparable and employed similar measurement techniques [17].

Sample 1: US Service Personnel

In service personnel Body mass was determined using The BOD POD (COSMED USA, Concord, CA, USA, software version 5.3.2) scale and participants evacuated their bladder before stepping onto the scales. Stature was recorded to the nearest 1 cm using a wall-mounted stadiometer (Tanita HR-200). Participants were assessed without shoes and wearing light clothing. WC measures were taken end tidal, using the superior border of the right iliac crest as a landmark. The measurement is taken three times, with the average of the three down to the nearest 0.1 cm recorded as the final value [16, page 24].

Sample 2: UK non-service participants from English Health & Wellbeing clinics

These data with associated methods have been previously published, see Nevill et al. [5]. Body mass was measured using digital scales (Marsden, UK) and recorded to the nearest 0.1 kg. Clothing was worn but shoes and belts were removed, and participants evacuated their bladder before stepping onto the scales. Stature was measured using a stadiometer (Seca, Hamburg, Germany) and recorded to the nearest 0.1 cm. Participants removed their shoes, stood on the platform with feet together, and head in the Frankfort plane. Buttocks and scapulae were in contact with the back of the stadiometer, shoulders relaxed with hands and arms loosely at the sides, and the measurement was taken on full inhalation. WC was measured with participants standing with feet shoulder width apart using a standard, non-elastic anthropometric tape measure (Seca, Birmingham, UK). WC measures were taken end tidal to the nearest 0.1 cm, midway between the lowest rib and the iliac crest, which corresponded with the level of the umbilicus.

Sample 3: UK non-service participants from HSE

The data for sample 3 has been published previously [6] with full measurement details provided. To summarize, body mass was measured with shoes and bulky clothing removed, using Soehnle, Seca and Tanita electronic scales with a digital display. Stature was measured to the nearest millimetre using a portable stadiometer with a sliding head plate, a base plate and three connecting rods marked with a metric measuring scale. Participants removed their shoes, stretched to their maximum height with their head positioned in the Frankfort plane. The waist was defined as the midpoint between the lower rib and the upper margin of the iliac crest. WC was measured using a tape with an insertion buckle at one end. The measurement was taken twice, using the same tape, and recorded to the nearest millimetre.

Statistical methods

We developed a simple body shape index for WC to be independent of height (HT) using the allometric power law,

$$WC=a\cdot HT^{b}\cdot\varepsilon \tag{1}$$

where a and b are the scaling constant and scaling exponents for the WC and ε is the multiplicative error ratio [5,18]. Age and sex were incorporated into the model by allowing 'a' to vary for either sex and each age group (age categories 20–29, 30–39, 40–49) to accommodate the likelihood that WC may rise and peak sometime during adulthood. The model can be linearized with a log-transformation, and multiple regression/ANCOVA can be used to estimate the height exponent for WC having controlled for both age and sex.

Chi-square tests of independence and tests for linear trend were performed to assess whether by adopting a 'high-risk' criterion/cut-off point of WHTR = 0.55, adopted by the USA Air Force (AF) (CSAF approved AF/SG's recommendation as of January 2022 [19]) or WHTR= 0.5 adopted by NICE [11], over penalize shorter rather than the taller individuals. The 'high-risk' cut-off points (equivalent to WHTR=0.55 and 0.5) for the waist-independent-of-height ratio (WHT•5R), identified using linear regression, were also assessed for such an association.

Results

Scaling waist circumference for differences in height

Using the US service personnel from Sample 1, the allometric power law model for WC (Eq. 1), identified the height exponent to be 0.418 (SEE=0.085; 95 % CI 0.251–0.585) having controlled for both age and sex, suggesting that to be independent of height (HT) the body shape index for WC should be $W.HT^{-0.5}$. Similar results were obtained when fitting the allometric model (Eq. 1) using the data from sample 3. The model identified the height exponent to be 0.483 (SEE=0.040; 95 % CI 0.404–0.562). ANCOVA also identified significant main effects of age ($P < 0.001$), sex ($P < 0.001$), and an age-by-sex interaction ($P = 0.048$), see Supplementary Fig. S1. The allometric power law model for WC using sample 1 was similar to that reported by Nevill et al. [5], using UK non-service personnel from sample 2, with the height exponent 0.528 (SEE=0.040; 95 % CI 0.449–0.607) having controlled for both age and sex. Once again, this supports the notion that the simple body shape index for WC to be independent of stature (HT) should be $WC.HT^{-0.5}$. The ANCOVA also identified significant main effects of age ($P < 0.001$) and sex ($P < 0.001$), and an age-by-sex interaction ($P = 0.011$), see Supplementary Fig. S2.

Waist-by-height (WHTR) cut-off points penalize shorter people; evidence from Sample 1

To confirm that the new 'at risk' cut-off points recommended by NICE (WHTR<0.5), and the 'at risk' cut-off points recommended by US DoD (WHTR≤0.55) will unfairly penalize shorter people, we tabulated the number of service personnel (Sample 1) above or below these cut-off points by height and by sex. By observing the bold 'at risk' percentages in Table 1, there is clear evidence that shorter individuals are being penalized more frequently than taller individuals, confirmed using χ^2 tests of independence (6/8 tests $P < 0.05$).

Waist-by-height (WHTR) cut-off points penalize shorter people; evidence from Sample 2

As with sample 1 above, we tabulated the number of UK non-service participants from English Health & Wellbeing clinics (Sample 2) above or below the same cut-off points by height and by sex. By observing the bold 'at risk' percentages in Table 2, there is clear evidence that shorter individuals are being penalized more frequently that taller individuals, confirmed using χ^2tests of independence (8/8 tests $P < 0.05$).

Waist-by-height (WHTR) cut-off points penalize shorter people; evidence from Sample 3

Using sample 3, Nevill et al. [13] were able to confirm that adopting the cut-off point of WHTR = 0.5, recommended by NICE, shorter people will be unfairly penalized. The percentage of people whose WHTR is ≥.5 increases systematically with SHORTER, not taller people, irrespective of age or sex — see the bold figures in *their* Table 2. All 10 chi-square tests of independence, and all 10 tests for linear trend confirmed that by adopting the cut-off point of WHTR = 0.5, shorter individuals will be over penalized, and taller people with be under penalized (all $P < 0.001$).

The same effect was found when adopting the cut-off point of WHTR = 0.55 recommended by the US DoD, using the data from sample 3. When we tabulated the number of non-service participants from the UK HSE non-service participants (Sample 3) above or below the WHTR = 0.55 cut-off point by age group, height and by sex, the same trend to over-penalize shorter people was observed, see Supplementary Table S1.

Identifying new waist-independent-of-height WHT•5R cut-off points (equivalent to WHTR=0.5 and 0.55)

To establish if adopting WHT•5R cut-off points equivalent to WHTR = 0.5 and 0.55, overcomes the tendency to penalize taller or shorter people, we used linear regression to predict the equivalent WHT•5R cut-off points (see Fig. 1), using data from sample 2. Fig. 1, shows a linear model for male and female participants that both appear to diverge from the origin (x = 0, and y = 0) but with a marginally steeper slope for males. The fitted regression equation is,

$$WHT\bullet5R= (0{\cdot}051^{*}(male) + 1{\cdot}284)^{*}WHTR \tag{2}$$

where the model (Eq. 2) estimates the female WHTR slope parameter to be B = 1.284 (SEE=0.001) as the baseline parameter, with the male WHTR slope parameter steeper by a small but significant increase ΔB = 0.051 (SEE=0.001) (SEE=Standard Error of Estimate). The term

Table 1
The number of service personnel classified as above or below the cut-off points using waist divided by height (WHTR) (a) WHTR > 0.5, and b) WHTR > 0.55 by height and by sex.

		cutWHTR_0.5				cutWHTR_0.55			
Sex	Height	.00	1.00	Total	%> .5	.00	1.00	Total	%> .55
Male	140.00	0	1	1	**1.00**	0	1	1	**1.000**
	160.00	4	4	8	**0.50**	8	0	8	**0.000**
	170.00	70	51	121	**0.42**	115	6	121	**0.050**
	180.00	149	74	223	**0.33**	216	7	223	**0.031**
	190.00	58	16	74	**0.22**	73	1	74	**0.014**
	200.00	8	1	9	**0.11**	9	0	9	**0.000**
	Total	289	147	436	0.34	421	15	436	0.034
Female	140.00	1	0	1	**0.00**	1	0	1	**0.000**
	150.00	10	4	14	**0.29**	14	0	14	**0.000**
	160.00	48	13	61	**0.21**	60	1	61	**0.016**
	170.00	59	8	67	**0.12**	66	1	67	**0.015**
	180.00	10	0	10	**0.00**	10	0	10	**0.000**
	Total	128	25	153	0.16	151	2	153	0.013

Three (3/4) χ^2tests of independence and three (3/4) χ^2tests for linear trend were significant $P < 0.05$ (note that only 2 females had WHTR>0.55, prohibiting any meaningful χ^2tests of significance)

Table 2
The number of non-service personnel from Sample 2 classified as above or below the cut-off points using waist divided by height (WHTR) (a) WHTR > 0.5, and b) WHTR > 0.55 by height and by sex.

		cutWHTR_0.5				cutWHTR_0.55			
Sex	Height	.00	1.00	Total	%> .5	.00	1.00	Total	%> .55
Male	150.00	0	1	1	**1.00**	0	1	1	**1.00**
	160.00	11	56	67	**0.84**	43	24	67	**0.36**
	170.00	273	820	1093	**0.75**	694	399	1093	**0.37**
	180.00	744	1480	2224	**0.67**	1609	615	2224	**0.28**
	190.00	313	383	696	**0.55**	552	144	696	**0.21**
	200.00	17	19	36	**0.53**	26	10	36	**0.28**
	Total	1358	2759	4117	0.67	2924	1193	4117	0.29
Female	150.00	8	10	18	**0.56**	13	5	18	**0.28**
	160.00	178	93	271	**0.34**	226	45	271	**0.17**
	170.00	238	85	323	**0.26**	301	22	323	**0.07**
	180.00	26	6	32	**0.19**	30	2	32	**0.06**
	190.00	2	0	2	**0.00**	2	0	2	**0.00**
	Total	452	194	646	0.30	572	74	646	0.11

Four (4/4) χ^2tests of independence and four (4/4) χ^2tests for linear trend were significant $P < 0.001$.

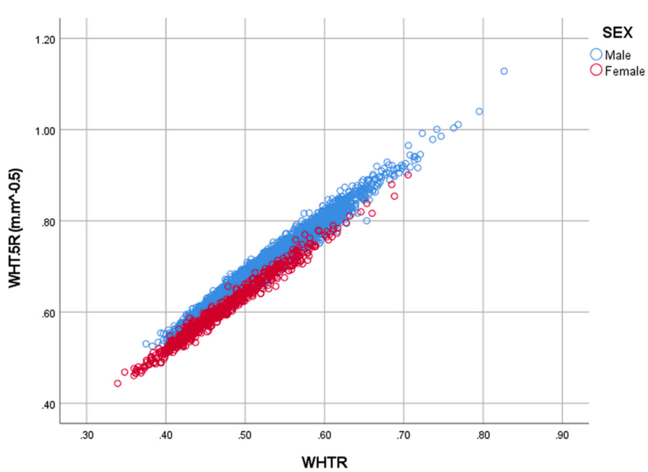

Fig. 1. The relationship between the waist independent-of-height ratio (WHT•5 R) and the waist-by-height ratio (WHTR) by sex from sample 2.

'male' represents a [0,1] indicator variable (0 female, 1 male) and WHT•5R are in the units ($m.m^{-0.5}$).

The model (Eq. 2; $R^2 = 99.9$ %; Mean Square Error (MSE)= 0.00016) predicts that cut-off points (equivalent to WHTR=0.5) for WHT•5R are 0.668 (male) and 0.642 (female). Cut-off points (equivalent to WHTR=0.55) for WHT•5 R are 0.734 (male) and 0.706 (female). Note that to record these cut-off points in the units ($in.in^{-0.5}$), the transformation/calculation is given by WHT•5R ($in.in^{-.5}$) = $\sqrt{39.37}$ * WHT•5R ($m.m^{-.5}$). For these WHT•5R ($in.in^{-0.5}$) cut-off points (equivalent WHTR=0.5) become 4.19 ($in.in^{-0.5}$) (male) and 4.03 ($in.in^{-0.5}$) (female), and the equivalent (WHTR=0.55) cut-off points for WHT•5R ($in.in^{-0.5}$) become 4.61 ($in.in^{-0.5}$) (male) and 4.43 ($in.in^{-0.5}$) (female).

Assessing bias using the waist-independent of height WHT•5R cut-off points; evidence from Sample 1

To assess whether the new WHT•5R 'at risk' cut-off points, predicted above, are less likely to penalize taller or shorter people, we tabulated the number of service personnel (Sample 1) above or below these cut-off points by height and by sex, see Table 3. By observing the bold 'at risk' percentages in Table 3, there is no evidence that shorter individuals are being penalized more or less frequently that taller individuals, confirmed using χ^2tests of independence (all 8/8 tests $P > 0.5$).

Assessing bias using the waist-independent of height WHT•5R cut-off points; evidence from Sample 2

To assess effectiveness of the new cut-off points for non-service personnel (sample 2), we again tabulated individuals above or below these cut-off points by height and by sex, see Table 4. By observing the

Table 3
The number of service personnel above or below waist divided by height$^{0.5}$ (WHT•5R) cut-off points by height and by sex.

		WHT•5R Cut-off_0.67m_0.643 f				WHT•5R Cut-off 0.734m_0.707 f			
Sex	Height	.00	1.00	Total	%>	.00	1.00	Total	%>
Male	140.00	0	1	1	**1.00**	1	0	1	**0.00**
	160.00	7	1	8	**0.13**	8	0	8	**0.00**
	170.00	86	35	121	**0.29**	121	0	121	**0.00**
	180.00	155	68	223	**0.30**	217	6	223	**0.03**
	190.00	53	21	74	**0.28**	72	2	74	**0.03**
	200.00	7	2	9	**0.22**	9	0	9	**0.00**
	Total	308	128	436	0.29	428	8	436	0.02
Female	140.00	1	0	1	**0.00**	1	0	1	**0.00**
	150.00	13	1	14	**0.07**	14	0	14	**0.00**
	160.00	52	9	61	**0.15**	60	1	61	**0.02**
	170.00	59	8	67	**0.12**	66	1	67	**0.01**
	180.00	8	2	10	**0.20**	10	0	10	**0.00**
	Total	133	20	153	0.13	151	2	153	0.01

Zero (0/4) χ^2tests of independence and zero (0/4) χ^2tests for linear trend were significant $P < 0.05$ (note that only 2 females had WHT•5R>707, prohibiting any meaningful χ^2 tests of significance)

Table 4
The number of non-service personnel above or below waist divided by height$^{0.5}$ (WHT•5R) cut-off points by height and by sex.

		WHT•5R Cut-off_0.67m_0.643f				WHT•5R Cut-off 0.734m_0.707f			
Sex	Height	.00	1.00	Total	%>	.00	1.00	Total	%>
Male	140.00	0	0	0	**0.00**	0	0	0	**0.00**
	160.00	0	1	1	**1.00**	0	1	1	**1.00**
	170.00	25	42	67	**0.63**	50	17	67	**0.25**
	180.00	371	722	1093	**0.66**	780	313	1093	**0.29**
	190.00	770	1454	2224	**0.65**	1591	633	2224	**0.28**
	200.00	251	445	696	**0.64**	506	190	696	**0.27**
	Total	11	25	36	0.69	23	13	36	0.36
Female	150.00	10	8	18	**0.44**	15	3	18	**0.17**
	160.00	190	81	271	**0.30**	234	37	271	**0.14**
	170.00	235	88	323	**0.27**	297	26	323	**0.08**
	180.00	24	8	32	**0.25**	30	2	32	**0.06**
	190.00	1	1	2	**0.50**	2	0	2	**0.00**
	Total	460	186	646	0.29	578	68	646	0.11

Zero (0/4) χ^2tests of independence and one (1/4) χ^2tests for linear trend were significant $P < 0.05$ (note that the female χ^2test for linear trend using WHT•5R>707 was significant)

bold 'at risk' percentages in Table 4, there is little or no evidence that shorter individuals are being penalized more or less frequently that taller individuals, confirmed using χ^2tests of independence (7/8 tests $P > 0.5$).

A simple shape chart for the waist-independent-of-height WHT•5R cut-off points (equivalent to WHTR=0.5 and 0.55)

Ashwell [20] published a Shape Chart for WHTR that allows an individual to match their waist measurement against their height to assess if they are at risk or not (see our WHTR Shape Chart Supplementary Table S2, based on the WHTR=0.5 and 0.55 cut-off points). Our results above show this will clearly penalize shorter individuals. Our equivalent WHT•5R Shape Charts (Tables 5-male & 6-female) provide a fairer, non-biased assessment of whether an individual is at risk.

Discussion

In this paper we confirm (using 3 large international samples) that by adopting WHTR cut-off points, shorter adults will be more frequently classified as being at risk and therefore unfairly penalized [10]. Here, we provide a simple solution using alternative WHT•5R cut-off points and shape charts. Adopting these alternative cut-off points will provide a fairer, non-biased assessment of whether an individual is at risk or not, based on a more appropriate method of normalizing WC for differences in height.

The importance of WC as a more sensitive anthropometric measure associated with obesity and health risk compared with, for example, BMI is recognised [1-6]. However, as Nevill, et al. [13] pointed out, unadjusted WC will always penalize taller subjects (taller people will have, on average, greater WC but not necessarily be at greater health or cardio-metabolic risk). Indeed, when scaling WC for differences in height using data from samples 1, 2, and 3, the allometric power law models identified the height exponents to be 0.418 (SEE=0.085; 95 % CI 0.251–0.585), 0.528 (SEE=0.040; 95 % CI 0.449–0.607), and 0.483 (SEE=0.040; 95 % CI 0.404–0.562) respectively, controlling for both age and sex, suggesting that the simple body shape index for WC to be independent of height (HT), should be $W.HT^{-0.5}$.

To overcome taller people being penalized, Ashwell et al. [1] suggest that WC should be divided by height to more fairly reflect the associated health risk with WC — they assume WHTR is independent of height and argue that the waist-to-height ratio (WHTR) is the strongest predictor of cardio-metabolic risk (CMR) in adults. However, as calculated using sample 1, Nevill et al. [5] reported that WC increases both theoretically and empirically in proportion to height raised to the power 0.5, and consequently, the new waist-by-height ratio, WHT•5R=$WC.Height^{-0.5}$, was found to be both independent of height but also a stronger predictor of CMR.

Our results (See Tables 1, 2 and S1) confirm that adopting the cut-off point of WHTR = 0.5 recommended by NICE or WHTR = 0.55 by the

Table 5
Male. The waist divided by height$^{0.5}$ (WHT•5R, in.in$^{0.5}$) Shape Chart with cut-off points WHTR≤4.19 (green; low risk), WHT•5R >4.19 to ≤4.61 (yellow; moderate risk) and WHT•5R >4.61 (red; high risk).

HT/W	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5	39.0	39.5	40.0	40.5	41.0	41.5	42.0	42.5	43.0	43.5	44.0
58	3.68	3.74	3.81	3.87	3.94	4.00	4.07	4.14	4.20	4.27	4.33	4.40	4.46	4.53	4.60	4.66	4.73	4.79	4.86	4.92	4.99	5.06	5.12	5.19	5.25	5.32	5.38	5.45	5.51	5.58	5.65	5.71	5.78
59	3.65	3.71	3.78	3.84	3.91	3.97	4.04	4.10	4.17	4.23	4.30	4.36	4.43	4.49	4.56	4.62	4.69	4.75	4.82	4.88	4.95	5.01	5.08	5.14	5.21	5.27	5.34	5.40	5.47	5.53	5.60	5.66	5.73
60	3.61	3.68	3.74	3.81	3.87	3.94	4.00	4.07	4.13	4.20	4.26	4.32	4.39	4.45	4.52	4.58	4.65	4.71	4.78	4.84	4.91	4.97	5.03	5.10	5.16	5.23	5.29	5.36	5.42	5.49	5.55	5.62	5.68
61	3.59	3.65	3.71	3.78	3.84	3.91	3.97	4.03	4.10	4.16	4.23	4.29	4.35	4.42	4.48	4.55	4.61	4.67	4.74	4.80	4.87	4.93	4.99	5.06	5.12	5.19	5.25	5.31	5.38	5.44	5.51	5.57	5.63
62	3.56	3.62	3.68	3.75	3.81	3.87	3.94	4.00	4.06	4.13	4.19	4.25	4.32	4.38	4.45	4.51	4.57	4.64	4.70	4.76	4.83	4.89	4.95	5.02	5.08	5.14	5.21	5.27	5.33	5.40	5.46	5.52	5.59
63	3.53	3.59	3.65	3.72	3.78	3.84	3.91	3.97	4.03	4.09	4.16	4.22	4.28	4.35	4.41	4.47	4.54	4.60	4.66	4.72	4.79	4.85	4.91	4.98	5.04	5.10	5.17	5.23	5.29	5.35	5.42	5.48	5.54
64	3.50	3.56	3.63	3.69	3.75	3.81	3.88	3.94	4.00	4.06	4.13	4.19	4.25	4.31	4.38	4.44	4.50	4.56	4.63	4.69	4.75	4.81	4.88	4.94	5.00	5.06	5.13	5.19	5.25	5.31	5.38	5.44	5.50
65	3.47	3.53	3.60	3.66	3.72	3.78	3.85	3.91	3.97	4.03	4.09	4.16	4.22	4.28	4.34	4.40	4.47	4.53	4.59	4.65	4.71	4.78	4.84	4.90	4.96	5.02	5.09	5.15	5.21	5.27	5.33	5.40	5.46
66	3.45	3.51	3.57	3.63	3.69	3.75	3.82	3.88	3.94	4.00	4.06	4.12	4.19	4.25	4.31	4.37	4.43	4.49	4.55	4.62	4.68	4.74	4.80	4.86	4.92	4.99	5.05	5.11	5.17	5.23	5.29	5.35	5.42
67	3.42	3.48	3.54	3.60	3.67	3.73	3.79	3.85	3.91	3.97	4.03	4.09	4.15	4.21	4.28	4.34	4.40	4.46	4.52	4.58	4.64	4.70	4.76	4.83	4.89	4.95	5.01	5.07	5.13	5.19	5.25	5.31	5.38
68	3.40	3.46	3.52	3.58	3.64	3.70	3.76	3.82	3.88	3.94	4.00	4.06	4.12	4.18	4.24	4.31	4.37	4.43	4.49	4.55	4.61	4.67	4.73	4.79	4.85	4.91	4.97	5.03	5.09	5.15	5.21	5.28	5.34
69	3.37	3.43	3.49	3.55	3.61	3.67	3.73	3.79	3.85	3.91	3.97	4.03	4.09	4.15	4.21	4.27	4.33	4.39	4.45	4.51	4.57	4.63	4.70	4.76	4.82	4.88	4.94	5.00	5.06	5.12	5.18	5.24	5.30
70	3.35	3.41	3.47	3.53	3.59	3.65	3.71	3.76	3.82	3.88	3.94	4.00	4.06	4.12	4.18	4.24	4.30	4.36	4.42	4.48	4.54	4.60	4.66	4.72	4.78	4.84	4.90	4.96	5.02	5.08	5.14	5.20	5.26
71	3.32	3.38	3.44	3.50	3.56	3.62	3.68	3.74	3.80	3.86	3.92	3.98	4.04	4.09	4.15	4.21	4.27	4.33	4.39	4.45	4.51	4.57	4.63	4.69	4.75	4.81	4.87	4.93	4.98	5.04	5.10	5.16	5.22
72	3.30	3.36	3.42	3.48	3.54	3.59	3.65	3.71	3.77	3.83	3.89	3.95	4.01	4.07	4.12	4.18	4.24	4.30	4.36	4.42	4.48	4.54	4.60	4.66	4.71	4.77	4.83	4.89	4.95	5.01	5.07	5.13	5.19
73	3.28	3.34	3.39	3.45	3.51	3.57	3.63	3.69	3.75	3.80	3.86	3.92	3.98	4.04	4.10	4.15	4.21	4.27	4.33	4.39	4.45	4.51	4.56	4.62	4.68	4.74	4.80	4.86	4.92	4.97	5.03	5.09	5.15
74	3.25	3.31	3.37	3.43	3.49	3.55	3.60	3.66	3.72	3.78	3.84	3.89	3.95	4.01	4.07	4.13	4.18	4.24	4.30	4.36	4.42	4.48	4.53	4.59	4.65	4.71	4.77	4.82	4.88	4.94	5.00	5.06	5.11
75	3.23	3.29	3.35	3.41	3.46	3.52	3.58	3.64	3.70	3.75	3.81	3.87	3.93	3.98	4.04	4.10	4.16	4.21	4.27	4.33	4.39	4.45	4.50	4.56	4.62	4.68	4.73	4.79	4.85	4.91	4.97	5.02	5.08
76	3.21	3.27	3.33	3.38	3.44	3.50	3.56	3.61	3.67	3.73	3.79	3.84	3.90	3.96	4.01	4.07	4.13	4.19	4.24	4.30	4.36	4.42	4.47	4.53	4.59	4.65	4.70	4.76	4.82	4.88	4.93	4.99	5.05
77	3.19	3.25	3.30	3.36	3.42	3.48	3.53	3.59	3.65	3.70	3.76	3.82	3.87	3.93	3.99	4.05	4.10	4.16	4.22	4.27	4.33	4.39	4.44	4.50	4.56	4.62	4.67	4.73	4.79	4.84	4.90	4.96	5.01
78	3.17	3.23	3.28	3.34	3.40	3.45	3.51	3.57	3.62	3.68	3.74	3.79	3.85	3.91	3.96	4.02	4.08	4.13	4.19	4.25	4.30	4.36	4.42	4.47	4.53	4.59	4.64	4.70	4.76	4.81	4.87	4.93	4.98

Table 6
Female. The WHT•5R (in.in$^{0.5}$) Shape Chart with cut-off points WHT•5R≤4.03 (green; low risk), WHT•5R >4.03 to ≤4.43 (yellow; moderate risk) and WHT•5R >4.43 (red; high risk).

HT/W	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5	39.0	39.5	40.0	40.5	41.0	41.5	42.0	42.5	43.0	43.5	44.0
58	3.68	3.74	3.81	3.87	3.94	4.00	4.07	4.14	4.20	4.27	4.33	4.40	4.46	4.53	4.60	4.66	4.73	4.79	4.86	4.92	4.99	5.06	5.12	5.19	5.25	5.32	5.38	5.45	5.51	5.58	5.65	5.71	5.78
59	3.65	3.71	3.78	3.84	3.91	3.97	4.04	4.10	4.17	4.23	4.30	4.36	4.43	4.49	4.56	4.62	4.69	4.75	4.82	4.88	4.95	5.01	5.08	5.14	5.21	5.27	5.34	5.40	5.47	5.53	5.60	5.66	5.73
60	3.61	3.68	3.74	3.81	3.87	3.94	4.00	4.07	4.13	4.20	4.26	4.32	4.39	4.45	4.52	4.58	4.65	4.71	4.78	4.84	4.91	4.97	5.03	5.10	5.16	5.23	5.29	5.36	5.42	5.49	5.55	5.62	5.68
61	3.59	3.65	3.71	3.78	3.84	3.91	3.97	4.03	4.10	4.16	4.23	4.29	4.35	4.42	4.48	4.55	4.61	4.67	4.74	4.80	4.87	4.93	4.99	5.06	5.12	5.19	5.25	5.31	5.38	5.44	5.51	5.57	5.63
62	3.56	3.62	3.68	3.75	3.81	3.87	3.94	4.00	4.06	4.13	4.19	4.25	4.32	4.38	4.45	4.51	4.57	4.64	4.70	4.76	4.83	4.89	4.95	5.02	5.08	5.14	5.21	5.27	5.33	5.40	5.46	5.52	5.59
63	3.53	3.59	3.65	3.72	3.78	3.84	3.91	3.97	4.03	4.09	4.16	4.22	4.28	4.35	4.41	4.47	4.54	4.60	4.66	4.72	4.79	4.85	4.91	4.98	5.04	5.10	5.17	5.23	5.29	5.35	5.42	5.48	5.54
64	3.50	3.56	3.63	3.69	3.75	3.81	3.88	3.94	4.00	4.06	4.13	4.19	4.25	4.31	4.38	4.44	4.50	4.56	4.63	4.69	4.75	4.81	4.88	4.94	5.00	5.06	5.13	5.19	5.25	5.31	5.38	5.44	5.50
65	3.47	3.53	3.60	3.66	3.72	3.78	3.85	3.91	3.97	4.03	4.09	4.16	4.22	4.28	4.34	4.40	4.47	4.53	4.59	4.65	4.71	4.78	4.84	4.90	4.96	5.02	5.09	5.15	5.21	5.27	5.33	5.40	5.46
66	3.45	3.51	3.57	3.63	3.69	3.75	3.82	3.88	3.94	4.00	4.06	4.12	4.19	4.25	4.31	4.37	4.43	4.49	4.55	4.62	4.68	4.74	4.80	4.86	4.92	4.99	5.05	5.11	5.17	5.23	5.29	5.35	5.42
67	3.42	3.48	3.54	3.60	3.67	3.73	3.79	3.85	3.91	3.97	4.03	4.09	4.15	4.21	4.28	4.34	4.40	4.46	4.52	4.58	4.64	4.70	4.76	4.83	4.89	4.95	5.01	5.07	5.13	5.19	5.25	5.31	5.38
68	3.40	3.46	3.52	3.58	3.64	3.70	3.76	3.82	3.88	3.94	4.00	4.06	4.12	4.18	4.24	4.31	4.37	4.43	4.49	4.55	4.61	4.67	4.73	4.79	4.85	4.91	4.97	5.03	5.09	5.15	5.21	5.28	5.34
69	3.37	3.43	3.49	3.55	3.61	3.67	3.73	3.79	3.85	3.91	3.97	4.03	4.09	4.15	4.21	4.27	4.33	4.39	4.45	4.51	4.57	4.63	4.70	4.76	4.82	4.88	4.94	5.00	5.06	5.12	5.18	5.24	5.30
70	3.35	3.41	3.47	3.53	3.59	3.65	3.71	3.76	3.82	3.88	3.94	4.00	4.06	4.12	4.18	4.24	4.30	4.36	4.42	4.48	4.54	4.60	4.66	4.72	4.78	4.84	4.90	4.96	5.02	5.08	5.14	5.20	5.26
71	3.32	3.38	3.44	3.50	3.56	3.62	3.68	3.74	3.80	3.86	3.92	3.98	4.04	4.09	4.15	4.21	4.27	4.33	4.39	4.45	4.51	4.57	4.63	4.69	4.75	4.81	4.87	4.93	4.98	5.04	5.10	5.16	5.22
72	3.30	3.36	3.42	3.48	3.54	3.59	3.65	3.71	3.77	3.83	3.89	3.95	4.01	4.07	4.12	4.18	4.24	4.30	4.36	4.42	4.48	4.54	4.60	4.66	4.71	4.77	4.83	4.89	4.95	5.01	5.07	5.13	5.19
73	3.28	3.34	3.39	3.45	3.51	3.57	3.63	3.69	3.75	3.80	3.86	3.92	3.98	4.04	4.10	4.15	4.21	4.27	4.33	4.39	4.45	4.51	4.56	4.62	4.68	4.74	4.80	4.86	4.92	4.97	5.03	5.09	5.15
74	3.25	3.31	3.37	3.43	3.49	3.55	3.60	3.66	3.72	3.78	3.84	3.89	3.95	4.01	4.07	4.13	4.18	4.24	4.30	4.36	4.42	4.48	4.53	4.59	4.65	4.71	4.77	4.82	4.88	4.94	5.00	5.06	5.11
75	3.23	3.29	3.35	3.41	3.46	3.52	3.58	3.64	3.70	3.75	3.81	3.87	3.93	3.98	4.04	4.10	4.16	4.21	4.27	4.33	4.39	4.45	4.50	4.56	4.62	4.68	4.73	4.79	4.85	4.91	4.97	5.02	5.08
76	3.21	3.27	3.33	3.38	3.44	3.50	3.56	3.61	3.67	3.73	3.79	3.84	3.90	3.96	4.01	4.07	4.13	4.19	4.24	4.30	4.36	4.42	4.47	4.53	4.59	4.65	4.70	4.76	4.82	4.88	4.93	4.99	5.05
77	3.19	3.25	3.30	3.36	3.42	3.48	3.53	3.59	3.65	3.70	3.76	3.82	3.87	3.93	3.99	4.05	4.10	4.16	4.22	4.27	4.33	4.39	4.44	4.50	4.56	4.62	4.67	4.73	4.79	4.84	4.90	4.96	5.01
78	3.17	3.23	3.28	3.34	3.40	3.45	3.51	3.57	3.62	3.68	3.74	3.79	3.85	3.91	3.96	4.02	4.08	4.13	4.19	4.25	4.30	4.36	4.42	4.47	4.53	4.59	4.64	4.70	4.76	4.81	4.87	4.93	4.98

USDoD, shorter people will be unfairly penalized. The percentage of people whose WHTR is ≥ .5 or ≥ .55 increases systematically with SHORTER, not taller people, see the bold figures in Tables 1, 2, and S1. When we assessed these trends, almost all of chi-square tests of independence and tests for linear trend confirmed that by adopting the cut-off point of WHTR = 0.5 or 0.55, shorter individuals will be over penalized, and taller people will be misclassified ($P < 0.001$). By dividing WC by height, as recommended by NICE and the USDoD, the original problem remains, it has been exacerbated but in the opposite direction! Based on these observations, shorter people could become unduly stressed by being misclassified (either WTHR >0.5 or >0.55), whilst taller individuals might be lulled into a false sense of security.

The solution is simple, by adopting the new cut-off points associated with the waist 'independent-of-height' ratio WC.Height$^{-0.5}$, the problem is either greatly reduced or eliminated. Using linear regression, the model predicts that the cut-off points (equivalent to WHTR=0.5) for WHT•5R are 0.668 (male) and 0.642 (female). The cut-off points (equivalent to WHTR=0.55) for WHT•5R are 0.734 (male) and 0.706

(female), all in the units (m.m$^{-0.5}$). The results reported in Tables 3 and 4 demonstrate that by adopting these new cut-offs, neither shorter nor taller people are likely to be misclassified as being at risk. Almost all of chi-square tests of independence and tests for linear trend confirmed no significant association between the new cut-off points and the height categories.

To illustrate our point using the current US sample 1, there is a shorter-than-average airman (165 cm or 65 in) whose body mass is 75 kg (165 lbs) and whose WC is 91.5 cm (36 in). His WHTR was calculated to be 0.554. He would be classified as 'at risk' and consequently would fail the body composition threshold (see Supplementary Table 2; red section). However, based on his WHT•5R, calculated as 0.712 (m.m$^{.5}$) or 4.47 (in.in$^{.5}$), his WC adjusted for height (using WHT•5 R) would be acceptable (Table 5; yellow section at moderate risk). Note that his BMI = 27.5 (kg.m^{-2}) is high because he lifts weights 5 days/week.

The current study examined two culturally distinct and independent samples of adults (US service personnel in sample 1 and two groups of UK non-service personnel in samples 2 and 3). — a strength of the current work, which demonstrates that classifying 'risk' using WHTR misclassifies both taller and shorter individuals in two independent samples. However, we are aware that the samples were not matched. This is a limitation and we would welcome future work examining the utility of WHT•5R in other groups to substantiate the results presented here.

One of the reasons authors and health professionals advocate the use of anthropometric indices such as BMI, WC and latterly waist-by-height related indices is due to the low cost and ease of administration of such metrics [3,21]. Importantly, the assessment of WHT•5R is no more time consuming than other anthropometric indices. Based on the data presented in the current manuscript however, WHT•5R provides a more precise anthropometric proxy, compared to simple WHTR, for use in both military, public and community health settings.

In summary, adopting WHTR cut-off thresholds (either 0.5 or 0.6, recommended by Ashwell et al. [1] or 0.55 recommended by the USDoD [12] will lead to shorter individuals being more frequently and thus unfairly classified as being 'at risk' in terms of their central adiposity body composition assessment and general health status. In contrast, adopting WHT•5R cut-off threshold points of 0.668 (male) and 0.642 (female) (m.m$^{-0.5}$) (equivalent to WHTR=0.5) or 0.734 (male) and 0.706 (female) (m.m$^{-0.5}$) (equivalent to WHTR=0.55), are likely to provide a fairer assessment process, since adopting an individual's WC measurement, adjusted for height using these new WHT•5R cut-off points, will not unfairly penalize either shorter or taller individuals, unlike the WHTR or unadjusted WC respectively. Clearly huge differences exist between male and female WC even having controlled for differences in height, see the supplementary Figures 1 and 2. For this reason, we recommend using (in all military, public, and community health settings) the male (Table 5) and female shape charts (Table 6) to provide a simple check for individuals to match their waist measurement against their height to more fairly assess whether they are at high, moderate, or low risk.

CRediT authorship contribution statement

AMN was responsible for conceptualisation, statistical analysis and writing original draft, review and editing and supervision. GDL, JM and GRHS were responsible for investigation, resources and writing, review and editing. TM was responsible for conceptualisation, visualisation, statistical analysis and writing review and editing. MJD was responsible for conceptualisation, visualisation, writing original draft, review and editing, and supervision.

Competing interests

The authors declare no competing interests.

Data availability

The data that support the findings of this study are available from the corresponding author, [AMN], upon reasonable request.

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The authors wish to thank all the US service personnel and UK participants for their valuable contributions when taking part in the study. The authors also wish to state that the views expressed in this article are those of the authors, and do not necessarily reflect the official position or policy of the United States Air Force, the Department of Defense, or the U.S. Government. This work is approved for public release.

Statement of ethical approval

Three independent samples were recruited. For sample 1 (US Service Personnel), investigators adhered to Department of Defense Instruction 3216.02 and 32 CFR 219, (see https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/321602p.pdf) on the use of volunteers in research. The reporting of secondary research data (originally collected for a non-research purpose) is exempt from IRB review. For sample 2 (non-service UK participants), institutional ethics approval was obtained from the University of Essex with written informed consent obtained prior to any data collection. For sample 3, ethics approval was obtained by the Health Survey for England (HSE) from the Oxford A Research Ethics Committee, Oxford B Research Ethics Committee, West London Research Ethics Committee and the East Midlands Nottingham 2 Research Ethics Committee.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.orcp.2023.01.002.

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