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Variability in body size and shape of UK Offshore Workers: a cluster analysis approach

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Abstract

Male UK offshore workers have enlarged dimensions compared with UK norms and knowledge of specific sizes and shapes typifying their physiques will assist a range of functions related to health and ergonomics. A representative sample of the UK offshore workforce (n=588) underwent 3D photonic scanning, from which 19 extracted dimensional measures were used in k-means cluster analysis to characterise physique groups. Of the 11 resulting clusters four somatotype groups were expressed: one cluster was muscular and lean, four had greater muscularity than adiposity, three had equal adiposity and muscularity and three had greater adiposity than muscularity. Some clusters appeared constitutionally similar to others, differing only in absolute size. These cluster centroids represent an evidence-base for future designs in apparel and other applications where body size and proportions affect functional performance. They also constitute phenotypic evidence providing insight into the 'offshore culture' which may underpin the enlarged dimensions of offshore workers.

Key Words: Offshore workers; body size; body shape; 3D scanning; cluster analysis

1. Introduction

1.1 Body size and occupational groups.

Variability in absolute and relative body size characterises all human populations. Amongst workers in specific industries such as firefighters and police, it is well recognised that individuals may differ from those of a host population, for instance by being taller and heavier (Hsiao et al., 2002). Such a difference has consequences for a range of factors including space provision, visibility of signage and optimising functionality and cost of equipment. Some body size differences between professional groups and the host population may exist as a consequence of recruitment, for example resulting from a height stipulation. Others may become increasingly prevalent with years of service, as a result of the nature and culture of the work environment, and its scope for developing specific muscle mass, or affecting energy balance. Over time, especially with legislative change within professions, the demographics of the occupational group itself may alter. All these factors coexist to determine the observable body size in a professional group at any one time, and have the potential to change it markedly over time. As a result, representative surveys of body dimensions within professional groups for vocationally-relevant sizing for clothing (Laing et al., 1999) and personal protective equipment (Hsaio et al., 2015) are appropriate, but may require regular updating in order to remain valid.

1.2 Physique classification using somatotype.

Genetic and environmental influences have the potential to render bodily physique almost infinitely variable. Much of this variation is usefully described using the somatotype approach originally proposed by Sheldon et al. (1940), and used subsequently either by the rating of photographs (Carter & Heath, 1990), or by anthropometric measurements (Heath & Carter, 1967). These yields a size-independent tri-axial physique rating which focuses on body proportions in terms of adiposity (endomorphy), musculo-skeletal development (mesomorphy) and linearity or relative weight (ectomorphy). In addition to phenotypes which exemplify these singular traits, more typically, a person's physique will reflect a combination of two or all three. While somatotyping might attract criticism for oversimplifying the complexity of body shape, any assessment of physique must balance accuracy with time taken to acquire measurements. While taking much longer than stature and mass assessments for body mass index (BMI) calculation, somatotype describes shape in a tissue specific manner which overcomes most of the inadequacies of BMI in failing to describe changes associated with ageing (Wells et al. 2008a), or inter-country or inter ethnic differences where centralisation of abdominal fat is pertinent (Wells et al. 2008b). Somatotyping is most commonly applied to child growth or athletes from different sports as a tool for tracking change or sporting talent identification. The technique has been also used in body image studies to identify desirable physiques (Stewart et al., 2014) but to date no somatotype studies of professional groups has been performed. 3D body scanning has augmented traditional anthropometry for describing physique by enabling cross sectional areas and segmental volumes to be extracted. This approach was successfully applied by Olds et al. (2013) using 29 measurements in a purposive sample of 305 individuals as part of a cluster analysis of military recruits. The result was that for both male and female groups, three physique clusters were selected, differing in the three primary physique classifications within somatotyping. However, as useful as somatotyping is, there are limitations to its size-independent schema in representing global physique variation, because larger individuals are not simply scaled up versions of smaller ones. In a sample of 478 athletes and non-exercising controls, taller individuals had greater relative leg length than their shorter counterparts, heavier individuals had disproportionately greater girths whereas differences in muscle mass and distribution related to the type (power, endurance, strength etc.) of sporting activity undertaken (Nevill et al., 2004). This suggest that cognisance needs to be taken of absolute as well as relative measures.

1.3 Survival suit design.

Designers of tools, clothing and transportation systems require information of absolute as well as relative size of populations in order to ensure their products are fit-for-purpose. Their challenge frequently includes balancing the available size / space with the cost of a range of sizing options. Although bespoke design may be an unnecessary luxury for most types of work and protective clothing, the design of survival suits might be an exception. Helicopter aviators worldwide face a small but significant risk of unintentional immersion in water which can result in irreversible cooling and lethal hypothermia (Tikuisis, 1999). In the UK continental shelf, 62,000 offshore workers are transported to installations by helicopter, wearing survival suits of a specified type, and clothing assemblages commensurate with the season. Each of the 11 commonly-worn survival suit sizes which aims to maximize the survival of the individual in the event of cold water immersion, but also optimise the dry ‘wearability’ and comfort for standing, walking and sitting. The wide variability of body shape pertaining to each size inevitably challenges designers. While the main fabric may stretch, a range of other features including zips, vents, pockets, reflective panels etc. are all required for the specification, and all impose constraints on the design. Personal fit preference is likely to vary between individuals, especially for those whose measurements are atypical for their overall body size. A tight-fitting suit will be better for cold water survival, while a looser fitting suit with larger air gaps may be more comfortable while worn dry, but more prone to water ingress which is likely to impair its performance by its extent and location (Tipton, 1997), and have higher buoyancy which is noted to hamper egress underwater (Brooks et al., 2001). While helicopter pilots may have made-to-measure survival suits, the vast majority of the UK offshore workforce will wear one of the established sizes of suit, broadly categorised by the person’s stature and chest girth.

Whether for survival suits, or other work wear or personal protective equipment, until recently, designers had no accurate data on the size of UK offshore workers to work from, relying either on historic data, assumptions and iteration from usage data. With clear evidence that the workforce is not typical of UK males, and is now anatomically larger than before (Stewart et al., 2015), the design process now has an unprecedented potential to ‘fit the design to the human’, rather than ‘fit the human to the design’, because of the much larger range of size and dimensional parameters now known in this vocational group. The aim of this study was therefore to characterise shape variability amongst UK offshore workers, both according to weight category, and also in terms of a key number of clusters based on natural size groupings within the workforce.

2. Methods

2.1 Sample.

Participants in this study are from the Size and Shape of Offshore Workers (SASOW) study (Ledingham et al., 2015) and recruited as a representative sample of the male UK offshore workforce aged 40.6 ± 10.7 y (mean ± SD). They were selected by quota sampling across seven weight categories (n = 588; 84 in each), which matched the most recently available data on body weight of the entire workforce. These categories were as follows in kg: <76.4; 76.5 - 82.4; 82.5 - 87.4; 87.5 - 91.4; 91.5 - 97.4; 97.5 - 104.4; >104.5. The sample size was selected in order to be equivalent or larger than the previous study of Light & Dingwall (1985) and to constrain the 95% confidence interval for the true workforce weight to 1.1 kg – a value which can be expected with the diurnal weight fluctuation. The sample selected individuals across these weight categories, matched almost perfectly to the most reliable reference weight for the offshore workforce, collected in 2009 [Chi-square value = 11.7; 11 df, P=0.613].

2.2 Measurements

Participants were professionals ‘core crew’ (who worked at least 50% time offshore) for whom all required data were available, recruited via a range of media from Oil & Gas UK and key stakeholders. Stature, mass and scan measurements took about 20 minutes and were acquired mostly at Aberdeen heliports but also in Norfolk which services the Southern North Sea sector. 3D body scans using an Artec L scanner (Artec Group, Luxembourg) wearing form-fitting shorts, and also with a full survival suit and lifejacket over their regular indoor clothing, standing erect, and also with arms and legs abducted, and also sitting, as described previously (Stewart et al., 2015). This involved arms being supported by orthopaedic walking poles, which were subsequently erased from the scanned images. Appropriate suit sizing was allocated according to manufacturer’s recommendations. Body mass index was calculated as a crude index to identify morphological similarities and differences between suit size groups.

Scans were processed and positioned using Artec studio 9 software (Artec Group, Luxembourg), prior to extracting 26 dimensional measurements which relied on visually identifiable landmark locations placed digitally on the scan surface, such as the axilla, nipple, naval and anterior knee, together with the most anterior, posterior or lateral aspects of convex surfaces. The measurements included linear distances, girths and segmental volumes, which are fully described in Ledingham et al. (2015) with reproducibility established using blinded re-analysis of 28 individuals . Of the measurements, 19 raw or derived measures were selected for analysis in the present study.

2.3 Statistical methods

Hierarchical cluster analysis was performed on an exploratory basis, which yielded 10 groups, plus one cluster with only one individual. Due to *a priori* knowledge of the range of suit sizes (n=11) which fitted the extant offshore population, it was decided to constrain the cluster analysis to this number and use k-means cluster analysis. The variables were: bideltoid breadth, shoulder girth, chest depth at deltoid, maximum chest depth, neck girth, chest breadth (axilla), chest breadth (nipple), chest girth, waist girth (minimum), waist girth (umbilicus), abdominal depth, hip girth, hip breadth (standing), hip breadth (sitting), wrist girth, buttock to knee (seated), % abdominal volume, % arm volume, % leg volume. Z-scores were derived for all 19 candidate variables, and the cluster analysis was based on these, to avoid large or small values resulting from units of measurement to dominate the clustering process. Centroids were identified as the person with the smallest Euclidean distance from the cluster mean. Clusters were then interrogated for raw dimensional data. For each of the seven weight categories and the 11 clusters, individuals whose global z scores were closest to zero were identified and analysed separately for phenotype using the photoscopic somatotype (Carter & Heath, 1990). The study was approved by Robert Gordon University Research Ethics Subcommittee.

3. Results

3.1 Reliability of measurements

The Artec L scanner has a 3D point accuracy of up to 0.2 mm and resolution of up to 1.0 mm, and had been previously benchmarked against an industry standard fixed scanner with a mean calibration error of 2.05% which included survival clothing (Ledingham et al., 2013). However, part of this difference is attributable to the horizontal array beam laser acquiring a less dense mesh than the Artec L scanner which uses structured light and acquires data from above and below horizontal, and thus provides more accurate detail. For the present study, technical error of measurement for extracted variables is summarised in Stewart et al. (2016a), and averaged 1.05% of measurement values.

3.2 Body mass index

Body mass index of individuals grouped by A) wearing the same survival suit size, and B) final clusters is summarised in figure 1.

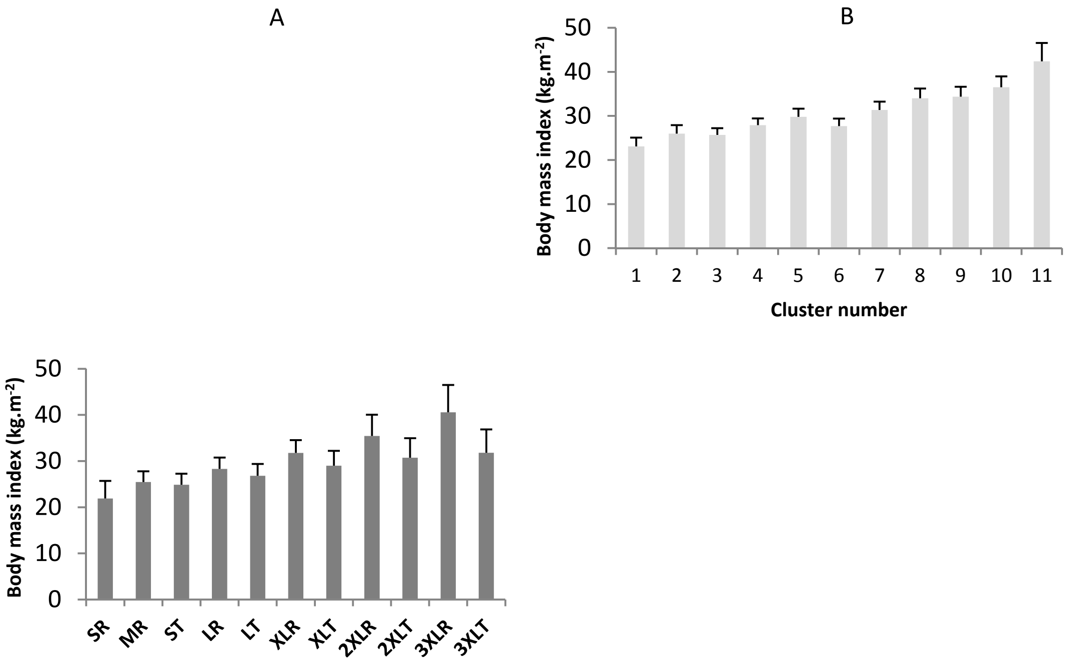

Figure 1. Body mass index of A) individuals wearing specified suit sizes; B) final clusters. Error bars refer to 1SD.

3.3 Weight categories

Mean Z scores across weight categories for selected variables are summarised in figure 2.

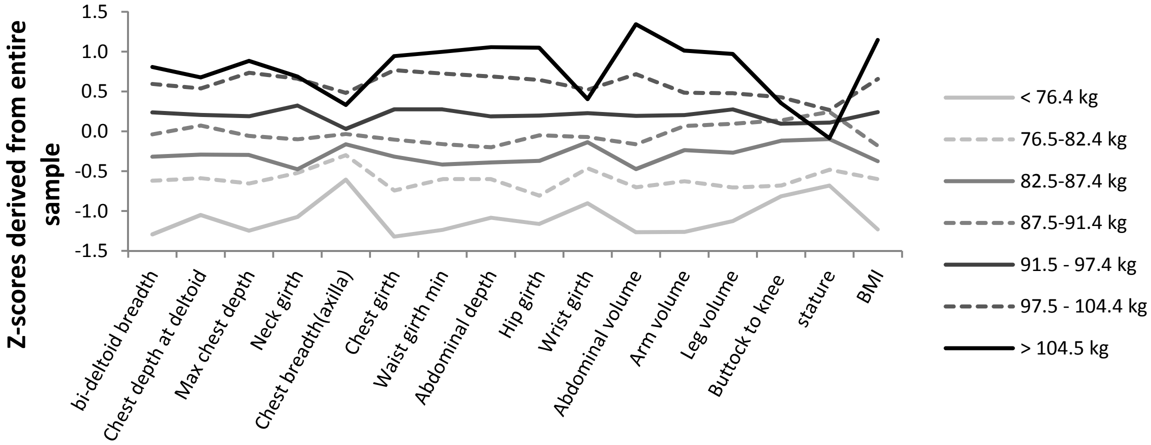

Figure 2. Mean Z scores of selected variables across weight categories (n=84 in each)

3.4 Somatotypes

Somatotypes according to weight category and cluster analyses are depicted in figures 3 and 4 respectively. These have been resolved to x-y coordinates as x = (ectomorphy – endomorphy) and y = 2* mesomorphy –(endomorphy + ectomorphy).

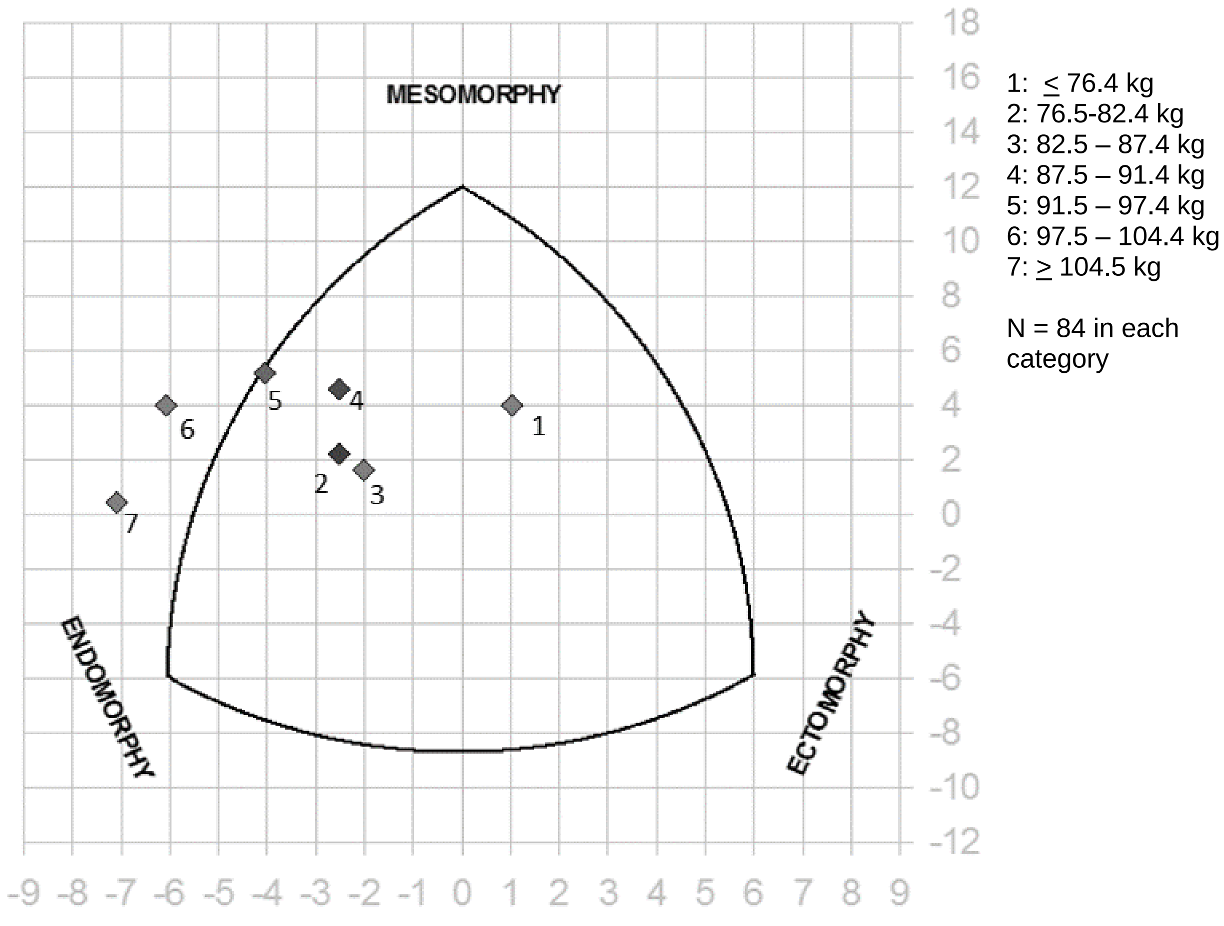

Figure 3. Somatotypes by weight category

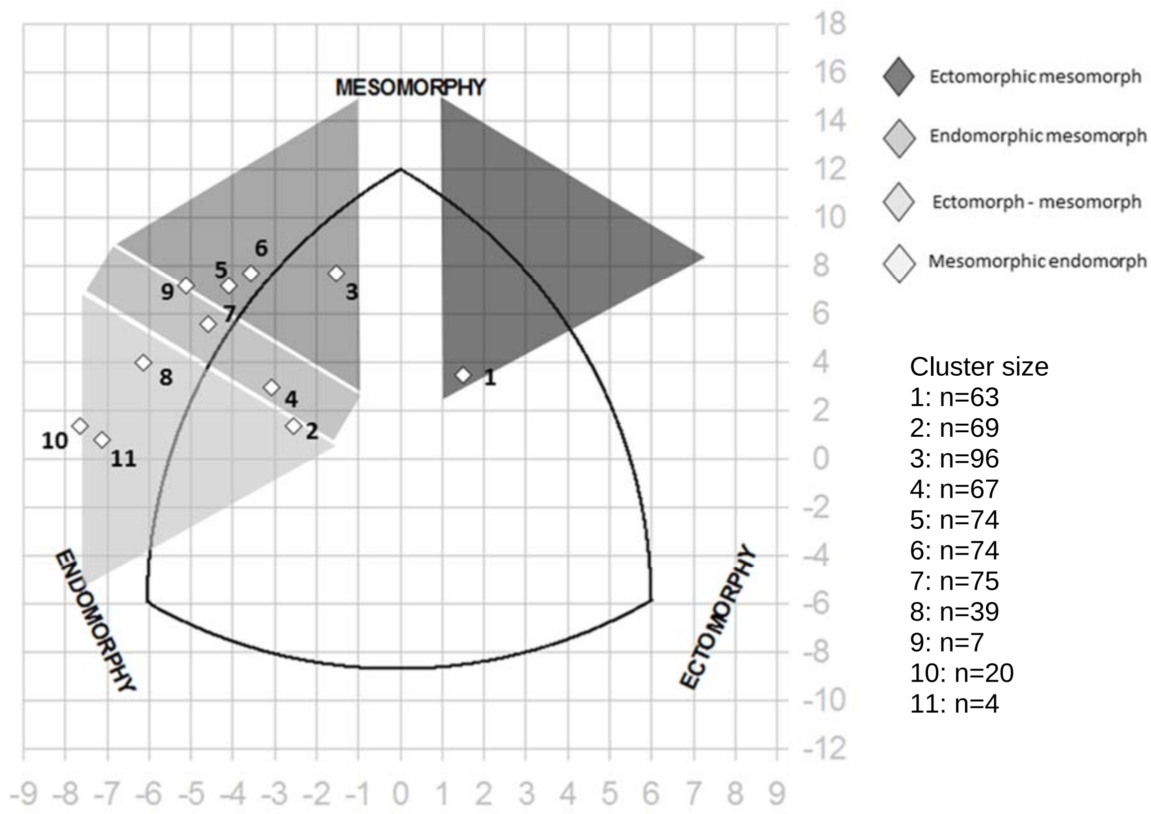

Figure 4. Somatotypes by cluster analysis, depicting nominal categories

The resulting physiques were spread across only 4 of the 10 possible nominal somatotype categories: ectomorphic mesomorphs (1 cluster); endomorphic mesomorphs (4 clusters); mesomorph-endomorphs (2 clusters) and mesomorphic endomorphs (4 clusters). Note that cluster centroids which appear close to one another on the somatochart may differ in absolute size. Somatotype images for the centroids of each cluster are depicted in figure 5.

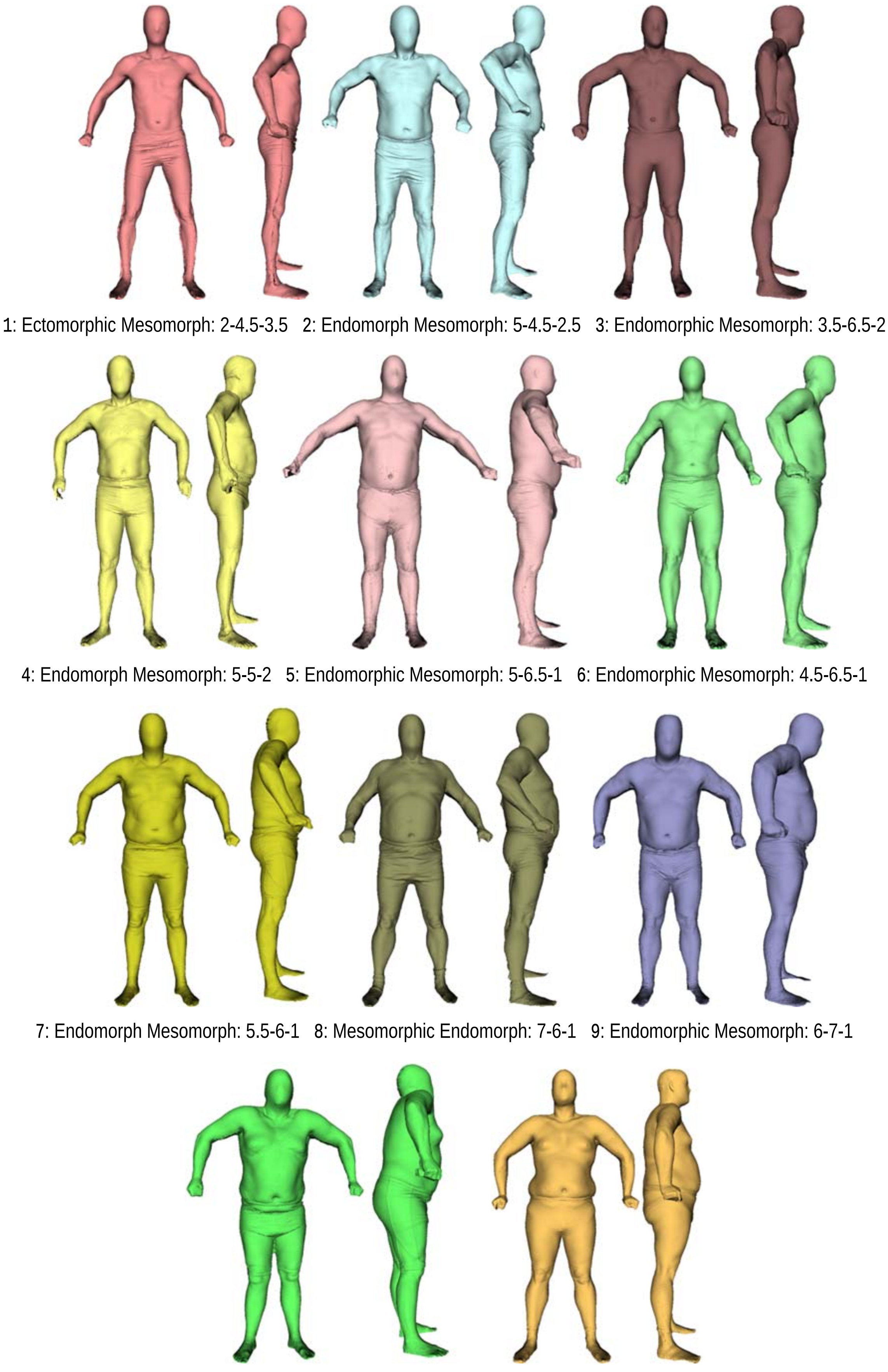

Figure 5. 3D scans of the centroids of the 11 clusters in somatotype pose

3.5 Dimensional data from the cluster analysis
Selected dimensional data from the clusters are summarised in table 1 and figure 6.

Table 1. Selected dimensional data and effect size of clusters

Cluster	Neck Girth	Shoulder girth	Chest Girth	Waist girth (minimum)	Hip girth
1 (n=63)	38.5 ± 1.6	117.9 ± 4.5	93.1 ± 3.4	81.9 ± 4.3	96.7 ± 3.2
2 (n=69)	40.3 ± 1.8	121.3 ± 4.4	100.8 ± 4.1	93.2 ± 4.5	99.2 ± 2.4
3 (n=96)	40.0 ± 1.8	127.4 ± 4.4	101.1 ± 2.9	89.0 ± 3.3	102.3 ± 2.5
4 (n=67)	41.9 ± 1.9	131.5 ± 5.1	108.1 ± 3.6	96.2 ± 4.5	108.3 ± 2.8
5 (n=74)	42.1 ± 1.9	126.7 ± 4.0	106.1 ± 2.8	97.7 ± 3.7	105.0 ± 2.7
6 (n=74)	43.3 ± 1.8	132.6 ± 5.0	111.5 ± 3.6	103.1 ± 4.0	105.9 ± 3.2
7 (n=75)	43.8 ± 2.0	136.4 ± 5.2	115.0 ± 3.3	106.3 ± 3.4	112.9 ± 3.4
8 (n=39)	46.8 ± 2.5	137.0 ± 4.9	119.8 ± 3.4	114.8 ± 4.8	113.0 ± 3.9
9 (n=7)	45.8 ± 2.2	151.5 ± 5.7	125.1 ± 7.3	111.9 ± 7.0	111.6 ± 3.3
10 (n=20)	47.1 ± 2.7	144.0 ± 5.5	124.9 ± 3.6	117.9 ± 3.8	119.7 ± 5.1
11 (n=4)	47.9 ± 3.7	148.9 ± 8.8	131.9 ± 5.7	127.4 ± 9.5	134.7 ± 5.9
Eta ^{2}	0.61	0.69	0.86	0.85	0.81

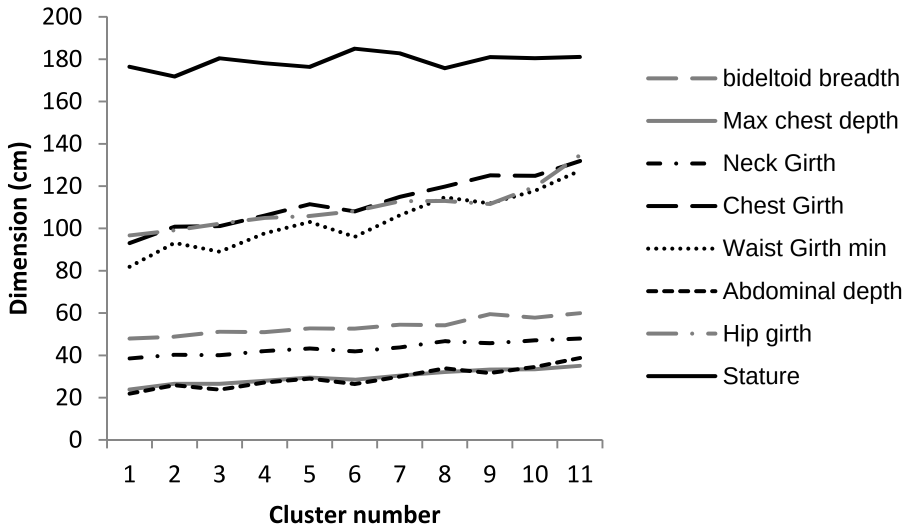

Figure 6. Selected dimensional data from clusters

4. Discussion

4.1 The physique of offshore workers
Unsurprisingly, individuals of different weight and with different cluster membership exhibited different absolute and relative morphological dimensions. While this is apparent via the crude body mass index comparison (figure 1), more detailed analysis (figure 2) shows those of heavier weight categories to appear broadly larger, but in a non-uniform pattern, whereby skeletal sites are less enlarged (e.g. thorax breadth) relative to soft tissue sites (e.g. waist girth). The cluster analysis yielded non uniform size increases between groups of increasing weight (figure 6), suggesting that the interaction of overall size and relative adiposity and

muscularity all contribute to the observed pattern. Universally, the explained variance (R^2 or Eta ^{2})by clustering exceeds that of BMI, despite BMI being a scale variable and clustering a nominal one. Furthermore, clustering encapsulates actual dimensional data as well as proportional data, and thus offers several advantages over BMI in relating a shape to a given size.

Cluster centroids represented only four nominal somatotype categories. While it could have been hypothesised that these would represent muscular and fat individuals, two rather striking observations emerge from the somatotype data. First, these physique clusters are not scattered throughout the somatochart, but concentrated in the endo - meso axis. Second, in the case of 7 clusters, the centroid plots outwith the somatochart, which was originally envisaged by Sheldon et al. (1940) to represent the likely extremes of possible physique variation. While the notion of fixed 'poles' between which physique might vary has long been superseded, it is nonetheless unusual that this professional group appears so far removed from physiques in other areas of the somatochart. One observational assessment required for photoscopic somatotyping is estimating the relative size of the abdominal and thoracic components of the trunk. In this study, the abdominal volume exceeds that of the thoracic volume in six of the 11 cluster centroids, a characteristic of high relative adiposity. The high mesomorphy (musculo-skeletal robustness) of some clusters may reflect the culture of strength training amongst offshore workers, but is harder to detect because significant muscle development may be partly obscured by overlying fat. In addition the mesomorphy score is calculated on both skeletal frame size as well as muscularity, so a centroid with a wider skeletal frame size will score higher, even if it is not especially muscular. Cluster 9's centroid, an endomorphic mesomorph, typifies a powerful build which has also significant overlying fat. In cluster 10's centroid – a mesomorphic endomorph, we see greater fat, and less visual evidence of muscle. By contrast, cluster 1's centroid has a physique which could be readily identifiable as athletic. There are two clusters (9 and 11) which have only 7 and 4 members respectively. Their physiques show a relatively rare combination of size and proportion which might be harder to accommodate in conventional sizing systems.

While rating of physiques has been criticised as subjective, akin to reading radiographs or scoring aesthetic sports where visio-spatial interpretation is required, its use in the present study is only to depict results from the cluster analysis. All somatotype ratings were undertaken by the same qualified practitioner, and can be seen as valid visualisations of shape which compliment other size-related data. The clusters of similar physique types express high levels of adiposity and to a lesser extent, muscularity. In relation to dimensional changes in the offshore workers observed since the 1980s, this observation concurs with the greatest increases in girth occurring at the abdomen and neck, sites renowned for adipose tissue accumulation. While it had previously been observed that offshore workers were 3% heavier and fatter than UK onshore counterparts (Light & Gibson, 1986), because the weight discrepancy has trebled since then, it is reasonable to conclude that fatness will have increased commensurately.

4.2 Possible explanations for physique disparity

Why offshore workers might be heavier, fatter or more muscular than the general population is the subject of considerable speculation. The explanation may relate to lifestyle choices imposed by the cyclical offshore – onshore shift pattern, which may have a cumulative effect on energy balance. Alternatively, there may be predisposition for a difference in lifestyle health risk factors which may result in more adverse health behaviours selected by those who have chosen to work offshore (Mearns & Hope, 2005). From the evidence cited in their study, both explanations are plausible. For instance, on offshore installations, highly palatable but less healthy food (e.g. deep fried) is the norm, portion sizes may be large and readily available, whereas healthy eating choices are limited. Other factors identified by Mearns & Hope may also be pertinent, such as eating as a result of stress, boredom or lack of self discipline. In addition to the adiposity, a large number of offshore workers assessed were overtly muscular. This may result from the culture of strength training which affects large numbers of workers, and some arduous manual work being carried out, despite enhancements in mechanisation over recent years. Age variability between clusters, ranged from 32 y (cluster 1) to 50 (cluster 8), suggesting age *per se* while affecting aspects of physique, is likely to be less influential than other factors, but because evidence elsewhere clearly shows that age affects physique (Wells et al. 2008a), it will remain a useful consideration as the profile of the workforce varies demographically.

4.3 Practical applications of clustering to categorise groups.

It has been previously established that UK offshore workers are larger than UK norms (Stewart et al., 2015), and as a consequence basing clothing design for on such norms for such an atypical professional group would be ill-judged. Hitherto, the industry has had little to go on except historic data collected more than three decades ago, aside from the closely monitored usage of different suit sizes, and a trial and error approach to new designs. Now the opportunity is available to consider precise dimensions represented by the dimensional database, or the clusters of common physiques, and develop designs which match these. This is important, because individuals with similar stature may have very different proportions, and the current guidelines based on stature and chest girth, are not designed to be formulaic. Recently it has emerged that heavier and larger workers are likely to have greater net buoyancy, which may approach or exceed the safe limit which is required to be overcome to escape a submerged helicopter (Stewart et al., 2016b). This underscores the need for better fitting designs which conform to the body shape and minimise trapped air. In addition to informing these, the use of clustering in medical diagnoses based on phenotype for a range of disorders including asthma (Moore et al., 2010) and spinal deformity (Stokes et al., 2009), cluster analysis has been already become established as an effective design tool in a number of contexts – for instance for firefighters' clothing (Laing et al., 1999) or gloves (Hsiao et al., 2015). While the use of clustering in examining shape for survival suit design is unprecedented, it has been used in textile research for quantifying air gaps in thermal protection using mannequins (Kim et al., 2002; Mah & Song, 2010). Traditional methods which calculated linear dimensions of individuals and the garments may have informed fitting issues, but are inadequate for elucidating the full complexity of the relationship between a body and the clothing worn (Lu et al., 2014). Testing different garments of variable size, thickness and stiffness, these authors used 3D scanning to investigate air gap distances, air volume and their distribution over the body. In their static model, they observed air gaps over convex areas were smaller than those over concave areas, and that the pelvis, chest and arms had small gaps, whereas the legs and abdomen had larger gaps. This observation on a standard mannequin (40 inch regular male in standard US size) has a visible narrowing at the waist, and this contrasts with observations of the majority of the clusters from the present study, where no narrowing exists. Furthermore, the volumetric increase when donning the survival suit is proportionally smallest for the largest and heaviest individuals (Ledingham & Stewart, 2013), suggesting that suit tightness of fit increases with body size. Whereas larger air gaps have been shown to decrease the severity of burns in flame retardant clothing (Kim et al., 2002), a smaller air gap would be advantageous in a survival suit, especially if water ingresses into this space, and subsequent flushing is amplified by wave action (Power et al., 2015). While the inherent buoyancy of a survival suit is affected by the amount of material, a better fitting suit will reduce the extent of trapped air built up which has the potential to be constrained by external pressure (e.g. via a lifejacket or a seatbelt), and thus not vented effectively on immersion.

Beyond the survival suit industry, offshore workers require specific work wear for a range of tasks. Cluster analysis not only may provide the detailed information for such industrial clothing design but will also create information which is of use on restricted space working, such as maintenance and decommissioning. Larger and ill-fitting suits have the potential to impair movement and create a snag hazard in restricted space settings. This is likely to prevail in other industries such including wind energy generation and a range of maintenance engineering tasks where the body's clearance space is restricted and workers must balance the requirement for access/egress, and the ability to carry out work tasks in restricted spaces.

4.4 Strengths and Weaknesses

This study, for the first time provides objective shape data of the UK offshore workforce, and natural groupings of physique types based on the variables extracted. It may be the case that the use of different extracted variables may yield different clusters, however those chosen were designed to represent anatomical regions which depict skeletal size, muscular development and excess fat accumulation. Other variables could have been extracted, but were not in the original study protocol. For instance, Schranz et al. (2010) used cross sectional areas and surface areas of limb segments in the identification of characteristics of elite rowers. However, the practicality of recruiting sufficient participants for the study required the majority of measuring to be performed at heliports, within a short acquisition time. This precluded the more time-consuming landmarking which would have been necessary for some of the variables they selected. In addition, the offshore sample was recruited by weight category and was predominantly Caucasian. Greater physique variability will be inevitable in a more heterogeneous sample, or in other parts of the world where other ethnicities are dominant. With these limitations, the study has provided new data which has laid the foundation for future design approaches. Cluster analysis factors in both size and shape, using whichever variables are adopted. Semi automated design of suits can be based on cluster centroids, and result in enhanced suit performance due to a closer fit and less trapped air. The economics of suit design and manufacture reflect the rarity of unusual sizes, and clustering acquires such information on all input dimensions, not merely stature and chest girth. Increasing digitisation of design and CAD modelling, already available for pilot suits, may make designs economically feasible for all offshore workers in future.

5. Conclusion and future work

Taken together, these 11 clusters represent groups of male offshore workers distinct from one another by size or proportion. These outperform BMI in describing shape, and differ from the clothing guideline approach adopted hitherto using stature and chest girth, by informing better designs of suit with less trapped air, enhanced performance and less excess material. Further exploration of clusters will assist the design process within and beyond the realm of safety clothing, which, with increasing digitisation and CAD modelling, may make even rare shape-size combinations economically feasible. Future work across a range of industries is likely to use clustering to optimise design both of clothing and the micro environment of those wearing it for work.

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