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Design and pattern engineering of the functional business, dress shirt for men

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Abstract
Conventional pattern grading systems for designing and mass-producing men's business, dress shirts involve anthropometric data collection, data interpretation, and application with respect to ergonomic performance. Such systems may not be able to meet the specific demand of Chinese male individuals with apple body shapes.

Although functional design tools are integral to apparel design because they increase the ease of movement, designers are generally unfamiliar with the design principles and application of pattern engineering design. This study proposes a method for measuring the dynamic anthropometric data of a potential user group in eight quasi-static office postures. Experiments were conducted to collect 20 measurements of seven Chinese male participants in both static and quasi-static office postures. One-way ANOVA was used to analyse the effects of key quasi-static office postures on the body measurements in a static state. These key measurements described the characteristics of the apple-shaped bodies. Subsequently, a method for analysing the woven garment–body relationship was used to determine key stress areas on the body in the key quasi-static office postures and to identify the location of functional design tools in pattern engineering design. Finally, the design principle of four-dimensional pattern engineering was proposed to create a functional business dress shirt design.

Keywords: functional men's business dress shirt; grading; apple body shape; pattern engineering design; dynamic anthropometric data

1. Introduction

Pattern grading is a mass production process that entails producing patterns of different sizes from an original master pattern (Cooklin 1992). The limitation of pattern grading is that this process is based on one-dimensional body measurements and does not consider the actual morphology and key body shape of a user (Schofield and LaBat 2005). Recently, apparel designers have been challenged by evolving social trends, such as the prevalence of abdominal obesity and the resulting apple-shaped bodies of male individuals of Chinese ethnicity. Ready-to-wear classic, men's graded dress shirts constitute a notable example of products with fitting problems related to users with apple-shaped bodies. Neck girth and sleeve length are the two major specifications that define sizes. In general, manufacturers produce shirts with two sleeve lengths per collar size to cater to a larger diversity of men in terms of the size (Karlen and Sulavik 1999; Sindicich and Black 2011). However, users with a nonstandard size, face difficulties in finding suitable products because they frequently encounter mismatches in sleeve length and anthropometric size (Pheasant 1987). Consequently, such users wear ill-fitting dress shirts that are a half size loose or tight in some body areas (Flusser 1996; Peres 2007). These problems present a critical research gap in determining a new solution of four-dimensional (4D) pattern engineering for achieving a robust design of functional business dress shirts for men. The current study was executed with the objective of addressing this gap. One of the principles of design is to determine dynamic anthropometric data of users. This is the main factor that adds the fourth dimension to the field of body dimensions through time and space when a body is performing different motions (Gupta et al. 2014).

2. Methodology

2.1 Collection of anthropometric data of a body in static and quasi-static office postures

Seven Chinese male participants aged 25–30 years were selected for this study. They exhibited a mean height of 175.30 cm, mean weight of 83.86 kg, mean body mass index of 27.29, indicating obesity (Center for Health Protection 2012), and mean waist-to-height ratio of 0.53, indicating an apple-shaped body (Hsieh and Yoshinaga 1995). Figure 1 presents the 37 anatomical landmarks that were identified according to the International Organization for Standardization (ISO) 8559-1989 standards to collect precise anthropometric data during static and quasi-static office postures. Landmarks were used because of the lack of measurement guidelines for male individuals with apple-shaped bodies. The landmarks were placed on the neck (8 markers), chest (10 markers), waist (8 markers), shoulders (2 markets), and arms (9 markers). Twenty body measurements were obtained for each participant: (a) nine girth measurements, namely neck, neck base, chest, waist, hip, armscye, upper arm, elbow, and wrist; (b) three width measurements, namely shoulder width, across front, and across back; and (c) eight length measurements, namely front waist, back waist, nape to waist, side seam, shoulder length, cervix to wrist, arm, and underarm.

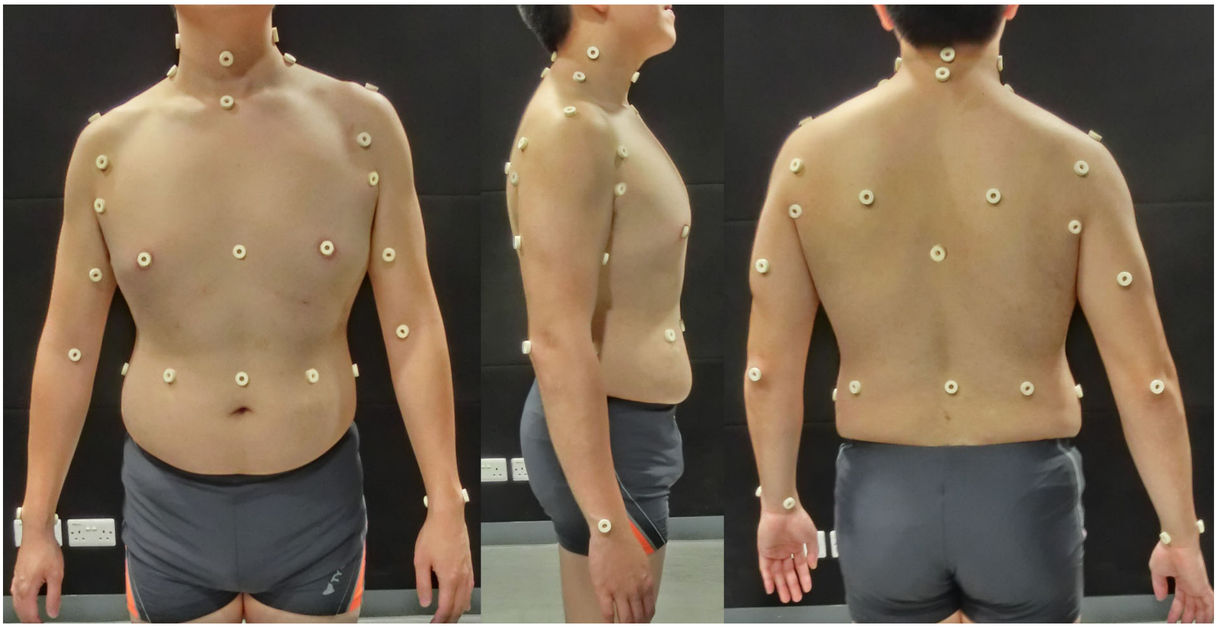


Figure 1: Anatomical landmarks.

Eight quasi-static office postures (figure 2-4) were selected from common posture variations identified among office workers (ANSI 2007; Ciccarelli et al. 2014; Pheasant 1987). The movements of major body joints, including the neck, shoulder and elbow, and waist joints, were investigated in the quasi-static postures: (a) head flexion 90^{o}, (b) head extension 30^{o}, (c) head lateral right 60^{o}, (d) head lateral left 60^{o}, (e) upright sitting 90^{o}, (f) bending hands forward, (g) trunk flexion 90^{o} and (h) trunk extension 30^{o}.

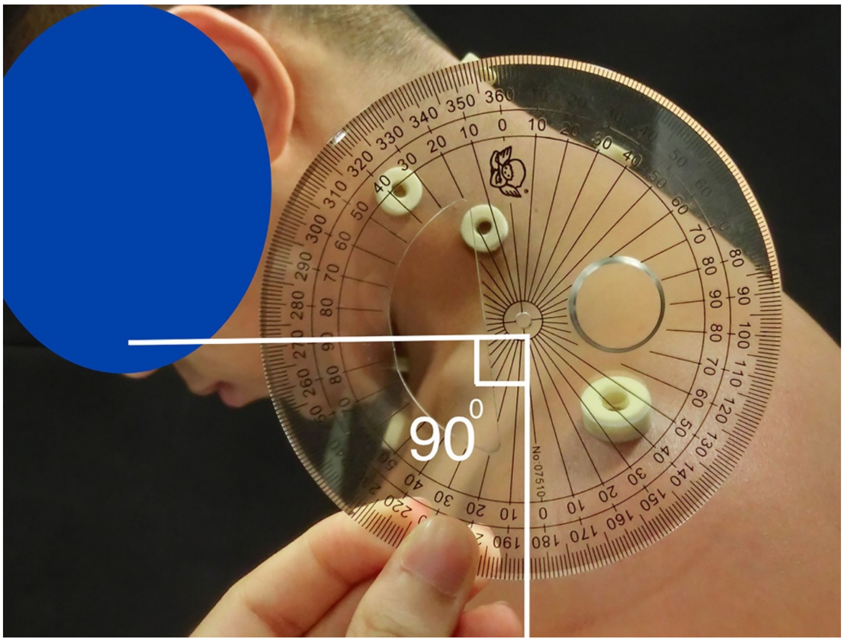


Figure 2a: Quasi-static office postures of neck movements - Head flexion 90^O.

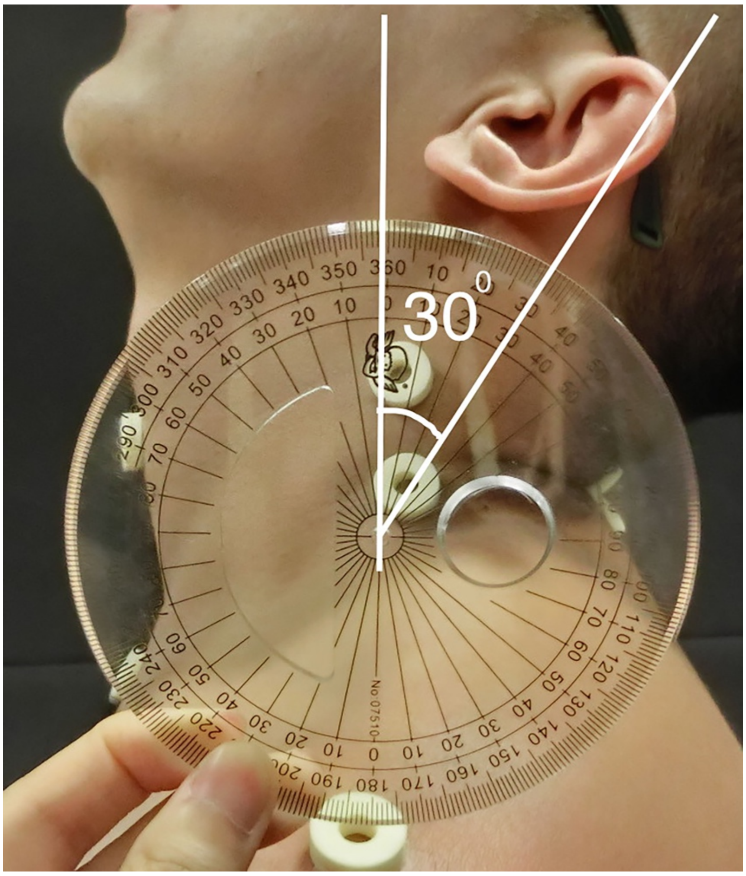


Figure 2b: Quasi-static office postures of neck movements - Head extension 30^O.

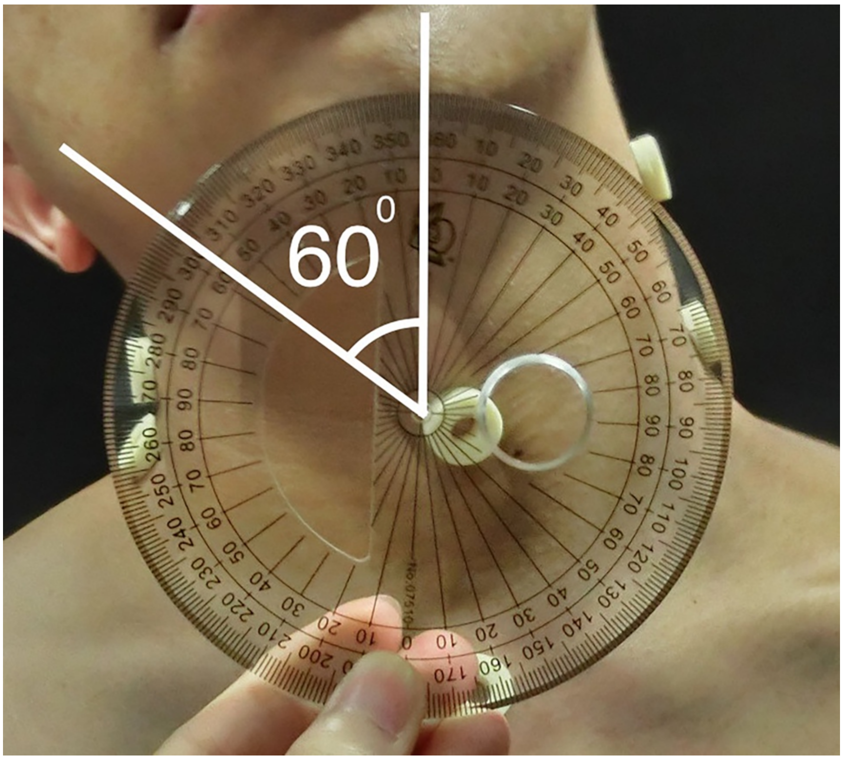


Figure 2c: Quasi-static office postures of neck movements - Head lateral right 60^{O}.

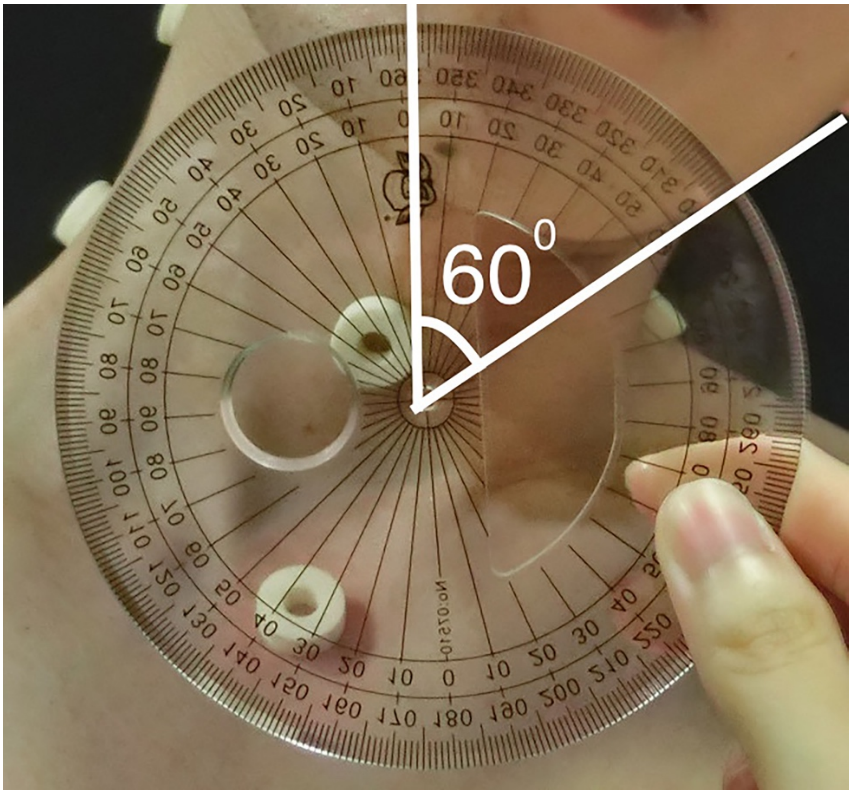


Figure 2d: Quasi-static office postures of neck movements - Head lateral left 60^{O}.

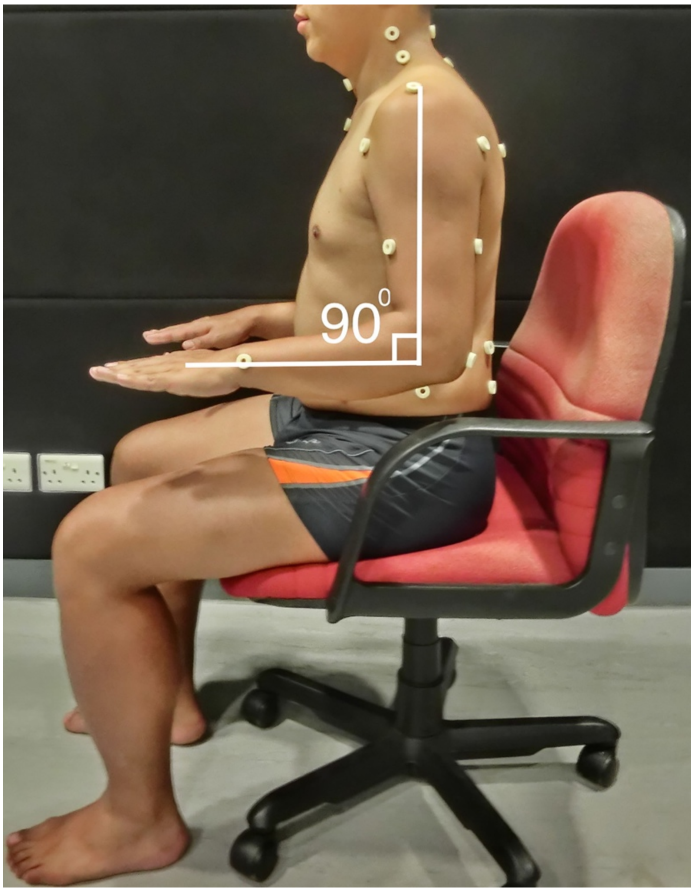


Figure 3a: Quasi-static office postures of the shoulder and elbow joint movements - Upright sitting 90^{o}.

Figure 3b: Quasi-static office postures of the shoulder and elbow joint movements - Bending hands forward.

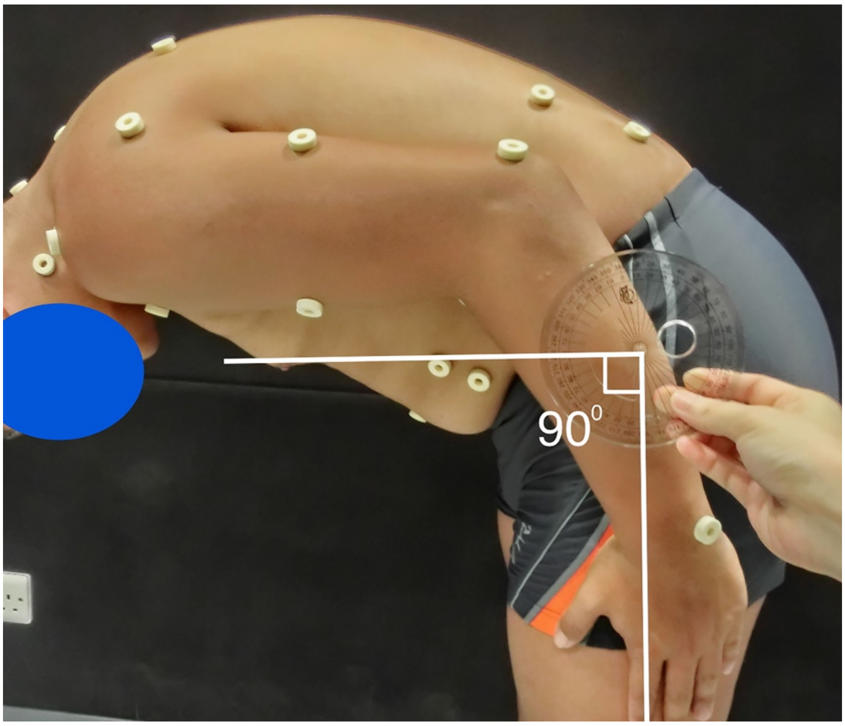


Figure 4a: Quasi-static office postures of the waist movements - Trunk flexion 90º.

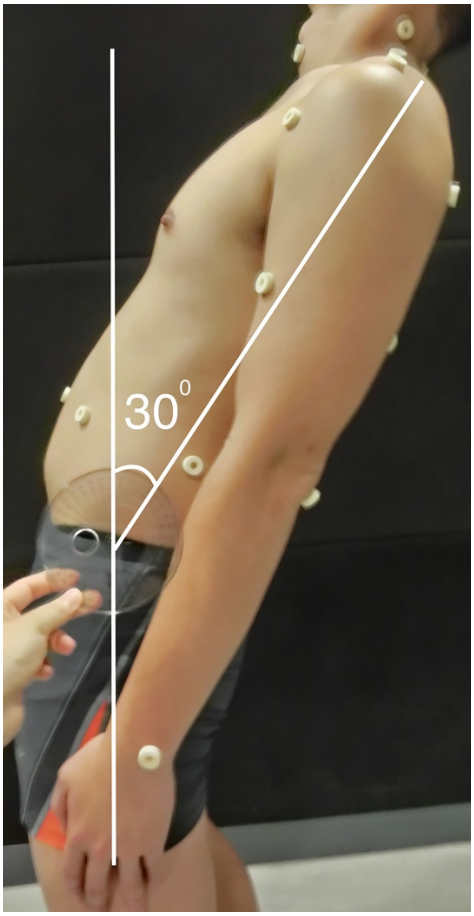


Figure 4b: Quasi-static office postures of the waist movements - Trunk flexion 30º.

A Vitus Smart XXL (Human Solutions) scanner for three-dimensional (3D) scanning and a measuring tape were used to obtain 20 measurements in static and quasi-static office postures. A goniometer was used to measure the range of motion (ROM) of the various body joints in these quasi-static postures. In the static posture, each participant wore a scan suit over his seminude body, stood on the foot markings on the base of the scanning machine in a relaxed static posture, and looked straight ahead with both arms away from his body (ISO 8559: 1989). Next, the participant was asked to perform the eight postures (figures 2-4). The same 20 measurements were collected in each posture. Each posture was repeated three times in order to calculate the mean measurement values to ensure the accuracy of each measurement.

2.2 Analyses of body anthropometric data

Descriptive statistics, including mean, standard deviation, percentage difference, and minimum and maximum values, were used to describe the characteristics of numerical body measurement data in the static standing posture, the differences between body measurements in the static standing and quasi-static office postures, and the suggested optimal ergonomic ease allowance values. A one-way analysis of variance (ANOVA) was performed to identify the key postures among the eight quasi-static office postures. By examining the effects of the identified key postures on each measurement, this study identified the key measurements among the 20 body measurements as the optimal ergonomic ease allowance values.

2.3 Stress body area analysis method

For this analysis, the same participants presented in Section 2.1 were recruited. The stress body area (SBA) analysis method (Chu et al. 2018) was adopted to investigate the woven garment–body relationship in terms of the degree of misfit and stress of the target garment during key quasi-static office postures. Four-slit garments similar to an industry-defined fitted silhouette in the ‘large’ size were created with vertical and horizontal slits at 45° and 135°, respectively, to detect eight types of stress directions in key postures. Each participant was asked to wear the four-slit garments while performing the key quasi-static postures. Identifiable landmarks were used to indicate stress patterns based on a participant’s postural differences. The deformation area between the identifiable landmarks was traced on the flat patterns.

2.4 Data analyses of the SBA analysis method

Through direct observations, the key SBAs of the participants were determined according to the common SBAs identified on the front, back, and sleeve panels of the four-slit garments. The key SBAs are the locations for placing the functional design tools.

2.5 Design and pattern engineering method

The design and 4D pattern engineering method were proposed in this study. Optimal ergonomic ease and the functional design tools were incorporated in the key SBAs in the pattern-making process to enhance the ROM of the wearer based on the anthropometric characteristics of the participants with apple-shaped bodies.

3.Results and discussion

3.1 Results of body measurements of participants in the static standing posture

Table 1 presents the results of 20 body measurements of the seven participants in the static standing posture.

Body measurements		Min. (cm)	Max. (cm)	Mean (cm)	Std. Dev
Girth	Neck	39.00	42.00	39.71	1.07
	Neck base	43.00	49.00	45.89	2.19
	Chest	100.60	110.30	103.44	3.25
	Armscye	46.00	50.00	48.57	1.51
	Waist	91.40	100.20	93.69	2.96
	Hip	102.90	115.60	106.56	4.16
	Upper-arm	29.20	33.50	31.09	1.40
	Elbow	25.50	27.50	26.63	0.72
	Wrist	15.60	18.00	16.89	0.80
Width	Shoulder width	41.20	46.50	43.16	2.03
	Across front	34.90	38.60	36.27	1.36
	Across back	35.00	40.00	37.70	1.61
Length	Front waist	42.40	49.60	45.07	2.76
	Back waist	44.70	48.60	46.77	1.27
	Nape to waist	40.00	45.60	42.37	1.75
	Side-seam	18.50	20.50	19.36	0.68
	Shoulder	12.00	13.80	12.87	0.70
	Arm	61.50	63.00	62.06	0.45
	Under-arm	40.30	42.30	41.59	0.82
	Cervical-to-wrist	81.80	84.20	82.57	0.88

Table 1: Body measurements of participants in static standing posture.

<u>3.2 Differences between body measurements in the static and quasi-static office postures</u>

Table 2 presents the differences in mean values and percentages of variation between body measurements in the static and quasi-static office postures.

Body measurements			Quasi-static postures							
			a	b	c	d	e	f	g	h
Girth	Neck (T)	Mean (cm)	0.43	2.00	0.50	0.71	0.00	0.00	-0.13	1.76
		[percentage: %]	(1.06)	(4.92)	(1.31)	(1.64)	(0.00)	(0.00)	(-0.32)	(4.44)
	Neck base (T)	Mean (cm)	-1.07	0.29	-1.00	-1.29	0.00	0.00	-0.83	1.40
		[percentage: %]	(-2.41)	(0.61)	(-2.11)	(-2.16)	(0.00)	(0.00)	(-1.84)	(3.04)
	Chest (T)	Mean (cm)	0.00	0.00	0.00	0.00	0.51	-2.04	5.53	0.46
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(0.51)	(-1.96)	(5.35)	(0.44)
	Armscye (T&A)	Mean (cm)	0.00	0.00	0.00	0.00	-1.00	2.21	1.59	1.67
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(-1.97)	(4.65)	(3.35)	(3.54)
	Waist (T)	Mean (cm)	0.00	0.00	0.00	0.00	5.83	1.74	3.91	1.83
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	**(6.24)**	(1.87)	(4.18)	(1.95)
	Hip (T)	Mean (cm)	0.00	0.00	0.00	0.00	**6.20**	0.00	-1.13	0.51
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(5.81)	(0.00)	(-1.07)	(0.48)
	Upper-arm (A)	Mean (cm)	0.00	0.00	0.00	0.00	1.41	2.01	0.00	0.09
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(4.59)	(6.51)	(0.00)	(0.28)
	Elbow (A)	Mean (cm)	0.00	0.00	0.00	0.00	2.40	**3.04**	0.00	0.06
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(9.04)	**(11.43)**	(0.00)	(0.22)
	Wrist (A)	Mean (cm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Remark: a = head flexion 90°, b = head extension 30°, c = head lateral right 60°, d = head lateral left 60°, e = upright sitting 90°,
f = bending hands forward, g = trunk flexion 90°, h = trunk extension 30°;
(T) = Torso, (A) = Arm; "+ve" = extension, "-ve" = contraction

Body measurements			Quasi-static postures							
			a	b	c	d	e	f	g	h
Width	Shoulder (T)	Mean (cm)	1.40	1.43	2.15	1.74	0.41	-2.93	-1.47	2.64
		[percentage: %]	(3.30)	(3.47)	(5.14)	(4.23)	(1.07)	(-6.66)	(-3.20)	(6.41)
	Across front (T)	Mean (cm)	-0.67	-0.24	-0.61	-0.57	-0.80	-11.84	-4.33	0.13
		[percentage: %]	(-1.87)	(-0.67)	(-1.70)	(-1.36)	(-2.15)	(-32.65)	(-11.80)	(0.45)
	Across back (T)	Mean (cm)	0.63	0.43	-0.56	-0.39	1.07	**5.01**	3.93	1.47
		[percentage: %]	(1.62)	(1.18)	(-1.50)	(-1.03)	(2.94)	**(13.37)**	(10.52)	(4.05)

Remark: a = head flexion 90°, b = head extension 30°, c = head lateral right 60°, d = head lateral left 60°, e = upright sitting 90°,
f = bending hands forward, g = trunk flexion 90°, h = trunk extension 30°;
(T) = Torso, (A) = Arm; "+ve" = extension, "-ve" = contraction

Body measurements			Quasi-static postures							
			a	b	c	d	e	f	g	h
Length	Front waist (T)	Mean (cm)	-2.04	0.56	-0.60	-0.09	-1.94	0.04	-7.97	2.77
		[percentage: %]	(-4.38)	(1.27)	(-1.27)	(-0.11)	(-4.20)	(0.14)	(-17.72)	(6.24)
	Back waist (T)	Mean (cm)	1.37	-1.54	-1.11	-1.24	-1.10	-1.81	1.59	-2.41
		[percentage: %]	(2.86)	(-3.30)	(-2.37)	(-1.35)	(-2.36)	(-3.90)	(3.45)	(-5.17)
	Nape to waist (T)	Mean (cm)	1.93	-1.83	-1.24	-1.14	-0.41	-0.90	**2.93**	-2.37
		[percentage: %]	(4.73)	(-4.35)	(-2.94)	(-2.70)	(-1.00)	(-2.14)	(6.94)	(-5.64)
	Side-seam (T)	Mean (cm)	0.00	0.00	0.00	0.00	-0.30	1.77	-0.40	-0.21
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(-1.42)	**(9.27)**	(-2.16)	(-1.06)
	Shoulder (T)	Mean (cm)	0.73	-0.04	0.66	1.10	0.33	-2.53	-0.30	0.43
		[percentage: %]	(5.44)	(-0.31)	(5.08)	(8.56)	(2.57)	(-19.71)	(-2.50)	(3.36)
	Arm (A)	Mean (cm)	0.00	0.00	0.00	0.00	**2.33**	1.94	0.87	-2.06
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	**(3.76)**	(3.13)	(1.39)	(-3.32)
	Under-arm (A)	Mean (cm)	0.00	0.00	0.00	0.00	-6.34	-5.73	0.29	-2.37
		[percentage: %]	(0.00)	(0.00)	(0.00)	(0.00)	(-15.24)	(-13.79)	(0.73)	(-5.69)
	Cervical-to-wrist (A)	Mean (cm)	0.70	0.33	0.10	0.04	1.76	-0.20	0.71	0.76
		[percentage: %]	(0.68)	(0.40)	(0.13)	(0.05)	(2.13)	(-0.24)	(0.88)	(0.92)

Remark: a = head flexion 90°, b = head extension 30°, c = head lateral right 60°, d = head lateral left 60°, e = upright sitting 90°,
f = bending hands forward, g = trunk flexion 90°, h = trunk extension 30°;
(T) = Torso, (A) = Arm; "+ve" = extension, "-ve" = contraction

Table 2: Differences between the body measurements in the static standing and quasi-static office postures.

Among all torso measurements listed in Table 2 (marked by 'T'), hip girth, across back width, and nape-to-waist length presented the most significant changes. For these measurements, the skin extended by 6.20 cm in the upright sitting 90⁰ (posture: e), by 5.01 cm during bending hands forward (posture: f), and by 2.93 cm during trunk flexion 90⁰ (posture: g). Regarding the percentage change, the skin extension for waist girth during upright sitting 90⁰ (posture: e), across back width and side-seam length during the posture of bending hands forward (posture: f), presented maximum percentage changes of 6.24%, 13.37%, and 9.27 %, respectively.

Chest girth and across front width presented maximum contractions of −2.04 and −11.84 cm, respectively, during the posture of bending hands forward (posture: f). Front waist length had a maximum contraction length of −7.97 cm during trunk flexion 90⁰ (posture: g). Regarding percentage change, skin contractions along the neck base girth during head flexion 90⁰ (posture: a), across front width and shoulder length during the same posture of bending hands forward (posture: f) presented maximum percentage changes of -2.41%, -32.65%, and -19.71%, respectively.

Regarding the arm measurements (marked by ‘A’), elbow girth and arm length had maximum extensions (maximum percentage changes in girth and length) of 3.04 cm (11.43%) during the posture of bending hands forward (posture: f) and 2.33 cm (3.76%) during the posture of upright sitting 90^0 (posture: e), respectively.

Armscye girth and underarm length had maximum contractions (maximum percentage changes in girth and length) of −1.00 cm (−1.97%) and −6.34 cm (−15.24%), respectively, during the posture of upright sitting 90^0 (posture: e). The wrist girth measurements did not change for all postures.

3.3 Key quasi-static office postures and key body measurements

One-way ANOVA ($p < 0.05$) was used to analyse the relationship between the 8 quasi-static office postures and 20 body measurements. Table 3 shows that the p values of all body measurements are more than 0.05, indicating nonsignificant measurement changes for the postures of head flexion 90^o, head extension 30^o, head lateral right 60^o, and head lateral left 60^o. Therefore, neck movements are not the key quasi-static office postures and were not considered in this study.

Body measurements		F	Sig.
Girth	Neck	0.237	0.639
	Neck base	0.392	0.549
	Chest	0.000	1.000
	Armscye	0.000	1.000
	Waist	0.000	1.000
	Hip	0.000	1.000
	Upper-arm	0.000	1.000
	Elbow	0.000	1.000
	Wrist	0.000	1.000
Width	Shoulder width	1.772	0.220
	Across front	1.277	0.291
	Across back	0.262	0.623
Length	Front waist	1.801	0.216
	Back waist	1.737	0.224
	Nape to waist	1.881	0.207
	Side-seam	0.000	1.000
	Shoulder	1.700	0.229
	Arm	0.000	1.000
	Under-arm	0.000	1.000
	Cervical-to-wrist	0.296	0.601

Table 3a: One-way ANOVA results for neck movements - Head flexion 90^0.

Body measurements		F	Sig.
Girth	Neck	1.658	0.234
	Neck base	0.015	0.906
	Chest	0.000	1.000
	Armscye	0.000	1.000
	Waist	0.000	1.000
	Hip	0.000	1.000
	Upper-arm	0.000	1.000
	Elbow	0.000	1.000
	Wrist	0.000	1.000
Width	Shoulder width	1.231	0.299
	Across front	0.151	0.708
	Across back	0.138	0.720
Length	Front waist	0.149	0.710
	Back waist	2.151	0.181
	Nape to waist	1.650	0.235
	Side-seam	0.000	1.000
	Shoulder	0.139	0.719
	Arm	0.000	1.000
	Under-arm	0.000	1.000
	Cervical-to-wrist	0.459	0.517

Table 3b: One-way ANOVA results for neck movements - Head extension 30^0.

Body measurements		F	Sig.
Girth	Neck	0.278	0.612
	Neck base	0.567	0.473
	Chest	0.000	1.000
	Armscye	0.000	1.000
	Waist	0.000	1.000
	Hip	0.000	1.000
	Upper-arm	0.000	1.000
	Elbow	0.000	1.000
	Wrist	0.000	1.000
Width	Shoulder width	0.319	0.588
	Across front	0.806	0.396
	Across back	0.130	0.727
Length	Front waist	0.140	0.718
	Back waist	1.448	0.263
	Nape to waist	0.708	0.424
	Side-seam	0.000	1.000
	Shoulder	17.967	0.103
	Arm	0.000	1.000
	Under-arm	0.000	1.000
	Cervical-to-wrist	0.153	0.706

Table 3c: One-way ANOVA results for neck movements - Head lateral right 60^0.

Body measurements		F	Sig.
Girth	Neck	0.958	0.356
	Neck base	0.250	0.631
	Chest	0.000	1.000
	Armscye	0.000	1.000
	Waist	0.000	1.000
	Hip	0.000	1.000
	Upper-arm	0.000	1.000
	Elbow	0.000	1.000
	Wrist	0.000	1.000
Width	Shoulder width	2.295	0.168
	Across front	1.672	0.232
	Across back	0.343	0.574
Length	Front waist	0.450	0.521
	Back waist	3.377	0.103
	Nape to waist	0.733	0.417
	Side-seam	0.000	1.000
	Shoulder	0.045	0.838
	Arm	0.000	1.000
	Under-arm	0.000	1.000
	Cervical-to-wrist	1.155	0.314

Table 3d: One-way ANOVA results for neck movements - Head lateral left 60^0.

As shown in Table 4a, upright sitting 90^0 had significant effects on five key measurements: (a) girth: waist ($p = 0.018$) and elbow ($p = 0.004$); (b) length: arm ($p = 0.016$), underarm ($p = 0.000$) and cervical-to-wrist ($p = 0.000$). The effects on the remaining measurements were not significant due to shoulder and elbow movements. As presented in Table 4b, bending hands forward caused significant changes in seven key measurements: (a) girth: elbow ($p = 0.001$); (b) width: shoulder width ($p = 0.017$), across front ($p = 0.000$), and across back ($p = 0.002$); (c) length: side-seam ($p = 0.013$), shoulder ($p = 0.001$), and underarm ($p = 0.001$). However, the effects on the remaining measurements were not significant.

Body measurements		F	Sig.
Girth	Neck	0.000	1.000
	Neck base	0.000	1.000
	Chest	0.017	0.898
	Armscye	0.182	0.681
	Waist	8.836	0.018*
	Hip	2.954	0.124
	Upper-arm	2.887	0.28
	Elbow	15.459	0.004*
	Wrist	0.000	1.000
Width	Shoulder width	0.036	0.885
	Across front	0.028	0.871
	Across back	2.608	0.145
Length	Front waist	1.796	0.217
	Back waist	1.610	0.240
	Nape to waist	0.087	0.776
	Side-seam	0.462	0.516
	Shoulder	0.536	0.485
	Arm	9.208	0.016*
	Under-arm	91.388	0.000*
	Cervical-to-wrist	43.917	0.000*

Table 4a: One-way ANOVA results for shoulder and elbow joint movements - Upright sitting 90⁰.

Body measurements		F	Sig.
Girth	Neck	0.000	1.000
	Neck base	0.000	1.000
	Chest	1.203	0.305
	Armscye	3.654	0.092
	Waist	0.154	0.705
	Hip	0.000	1.000
	Upper-arm	3.230	0.110
	Elbow	27.112	0.001*
	Wrist	0.000	1.000
Width	Shoulder width	8.964	0.017*
	Across front	123.973	0.000*
	Across back	21.950	0.002*
Length	Front waist	0.003	0.954
	Back waist	3.630	0.093
	Nape to waist	0.376	0.557
	Side-seam	10.179	0.013*
	Shoulder	25.754	0.001*
	Arm	2.219	0.175
	Under-arm	24.611	0.001*
	Cervical-to-wrist	0.009	0.928

Table 4b: One-way ANOVA results for shoulder and elbow joint movements - Bending hands forward.

Table 5a presents that trunk flexion 90^0 had significant effects on five key measurements: (a) girth: chest ($p = 0.048$) and armscye ($p = 0.028$); (b) width: across front ($p = 0.002$) and across back ($p = 0.010$); (c) length: front waist ($p = 0.007$). The effects on the remaining measurements were not significant due to waist movements. As revealed by the results in Table 5b, trunk extension 30^o had significant effects on five key measurements: (a) girth: neck ($p = 0.038$); (b) length: back waist (p =

0.032), arm (p = 0.030), underarm (p = 0.016), and cervical-to-wrist (p = 0.028). The effects on the remaining measurements were not significant due to waist movements.

Body measurements		F	Sig.
Girth	Neck	0.029	0.868
	Neck base	1.007	0.345
	Chest	2.786	0.048*
	Armscye	7.221	0.028*
	Waist	2.480	0.154
	Hip	0.121	0.737
	Upper-arm	0.002	0.964
	Elbow	0.016	0.903
	Wrist	0.000	1.000
Width	Shoulder width	2.403	0.160
	Across front	19.268	0.002*
	Across back	11.223	0.010*
Length	Front waist	12.846	0.007*
	Back waist	4.199	0.075
	Nape to waist	3.521	0.097
	Side-seam	0.013	0.912
	Shoulder	0.038	0.850
	Arm	2.155	0.180
	Under-arm	0.346	0.572
	Cervical-to-wrist	2.096	0.186

Table 5a: One-way ANOVA results for waist movements - Trunk flexion 90^{o}.

Body measurements		F	Sig.
Girth	Neck	6.127	0.038*
	Neck base	0.827	0.390
	Chest	0.087	0.775
	Armscye	2.093	0.186
	Waist	0.686	0.431
	Hip	0.036	0.855
	Upper-arm	0.008	0.930
	Elbow	0.030	0.866
	Wrist	0.000	1.000
Width	Shoulder width	3.296	0.107
	Across front	0.542	0.483
	Across back	2.914	0.126
Length	Front waist	1.666	0.233
	Back waist	6.675	0.032*
	Nape to waist	2.550	0.149
	Side-seam	0.008	0.933
	Shoulder	0.990	0.349
	Arm	6.896	0.030*
	Under-arm	9.364	0.016*
	Cervical-to-wrist	7.210	0.028*

Table 5b: One-way ANOVA results for waist movements - Trunk extension 30^{o}.

3.4 Determination of the optimal ergonomic ease values in the key body measurements

Quasi-static office postures significantly influencing body measurements were identified as key postures: upright sitting 90º, bending hands forward, trunk flexion 90º, and trunk extension 30º. These postures significantly influenced 15 body measurements, which were identified as key body measurements: (a) five girth measurements, namely neck, chest, armscye, waist, and elbow; (b) three width measurements, namely shoulder width, across front, and across back; and (c) seven length measurements, namely front waist, back waist, side-seam, shoulder, arm, underarm, and cervical-to-wrist. These key body measurements exhibited maximum changes in the mentioned key postures (Section 3.2) and were thus considered as optimal ergonomic ease values. The results are summarised in Table 6.

Key body measurements		Ergonomic ease value	
		cm	%
Girth	Neck	1.76	4.44
	Chest	5.53	5.53
	Armscye	2.21	4.65
	Waist	5.83	6.24
	Elbow	3.04	11.43
Width	Shoulder width	2.64	6.41
	Across front	0.13	0.45
	Across back	5.01	13.37
Length	Front waist	2.77	6.24
	Back waist	1.59	3.45
	Side-seam	1.77	9.27
	Shoulder	0.43	3.36
	Arm	2.33	3.76
	Under-arm	0.29	0.73
	Cervical-to-wrist	1.76	2.13

Table 6: Optimal ergonomic ease values in key body measurements.

3.5 Identification of key SBAs for key quasi-static office postures

In this study, key quasi-static office postures of upright sitting 90º and bending hands forward were selected for in-depth analyses of 4D pattern engineering design.

As presented in Table 7, the front waist and elbow were identified as the key SBAs during the posture of upright sitting at 90°; this is because the common SBA patterns were found in the front panel and sleeve panel. Moreover, the back of the shoulder, across back, back chest, and elbow were identified as the key SBAs during the posture of bending hands forward (Table 8); this is because the common SBA patterns were found in the back panel and sleeve panel.

Pattern panel	Stress body area	Stress pattern found in four directions				Key stress body area
		V	H	45^{o}	135^{o}	
Front	In between chest and high hip	✓	x	✓	✓	Waist
Back	In between HPS and across back /In between HPS and chest	✓	x x	✓	✓	N/A
	In between chest and high hip	x	x	✓	✓	
Sleeve	In between bicep and wrist /In between cap and mid of elbow and wrist	✓	✓	✓	✓	Elbow

Table 7: Results of SBA analysis for upright sitting 90^{0}.

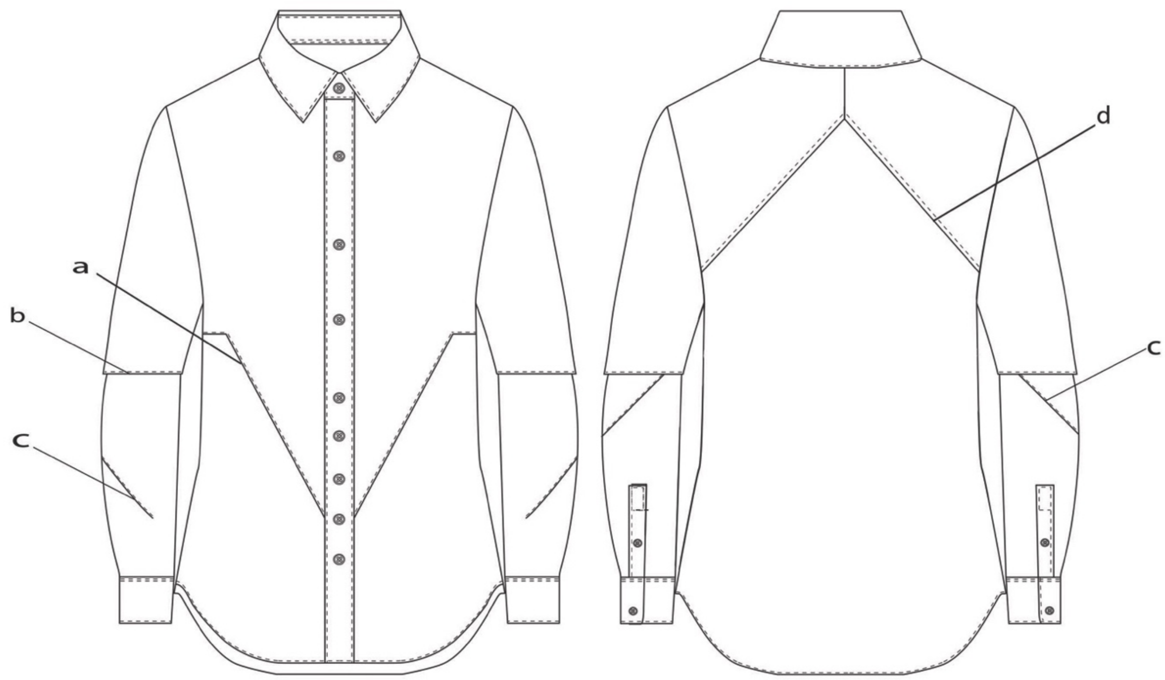
Pattern panel	Stress body area	Stress pattern found in four directions				Key stress body area
		V	H	45^{o}	135^{o}	
Front	In between waist and high hip	x	x	✓	✓	N/A
Back	In between HPS and high hip /In between HPS and waist /In between shoulder and waist	✓	x x x	✓	✓	-Shoulder -Across back -Chest
Sleeve	In between cap and wrist /In between bicep and wrist	✓	✓	✓	✓	Elbow

Table 8: Results of SBA analysis for bending hands forward.

4. Design and pattern engineering of men's functional business, dress shirt

Figures 5 and 6 illustrate a rough sketch and flat drawing of a prototype functional business dress shirt for men, respectively. The key SBAs (Tables 7 and 8) identified in this study were considered as the locations for the placement of functional design tools for two key quasi-static postures. For the upright sitting 90^{0}, a 45^{0} functional design tool was suggested to be at the front waist of the front panel. For the posture of bending hands forward, a 135^{0} functional design tool was suggested to be between the across back and back chest level at the back panel. A horizontal functional design tool and 135° functional design tool were suggested at the elbow level; these tools should pass through the elbow level and the forearm level of the sleeve panel, respectively. The functional design tools were combined into a single sleeve panel design with no conflicts by considering that the user would perform the two key postures on a daily basis. 5 of the 15 optimal ergonomic ease values (Table 6), chest girth, waist girth, elbow girth, across back width, and arm length were selected and incorporated into the functional design tools based on the determined locations of the key SBAs for the two key postures.

Figure 5: Rough sketch.



(a) 45⁰ functional design tool, (b) horizontal functional design tool, (c) 135⁰ functional design tool, and (d) 135⁰ functional design tool.

Figure 6: Design flat drawing.

5. Conclusion

This paper presents design ideas for a functional business, dress shirt for men through a rough sketch and flat drawing. This study considered the design principle of 4D pattern engineering that entails dynamic anthropometric data collection, interpretation, and application in the practice of pattern engineering. Changes in the body measurements in key quasi-static office postures were statistically determined to define 15 optimal ergonomic ease values for male Chinese office workers with apple-shaped bodies. Regarding the design ideas, 5 of the 15 optimal ergonomic ease values were incorporated into functional design tools located at suggested key SBAs on the front, back, and sleeve panels for selected key quasi-static office postures.

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