ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2018 SESSION

Open-book examination
Calculators : Only authorized models
Duration : 3 hours

14-IN-B2 Ergonomics

1) Considering normal work clothing, determine the values to accommodate 95% of industrial workers (males and females) for the following elements (justify your answers with calculus **using the anthropometric data provided in appendix**):

   a) Minimum and maximum height of an adjustable work seat used to make precision work on a 91 cm high worktable. (10 pts)
   b) Minimum and maximum height of an adjustable worktable used to make coarse assembly in a standing posture. (10 pts)
   c) The fixed height of the center of an adjustable control screen on a CNC machine, considering a reading distance of 48 cm. (10 pts)

2) A 52 years old female worker with an average fitness level and weighing 60 Kg carries out a task using the whole body, for which the average energy expenditure is estimated at 2.4 Kcal/min. Can this task be carried out for an 8 hours shift? Justify your answer. (10 pts)

3) Why is it said that tasks requiring both force and precision are generally incompatible with muscle anatomy and physiology? (5 pts)

4) Based only on heart rate, what are the different physiological criteria that can be used to determine if a task in acceptable for a given worker (10 pts)?

5) List and discuss the different risk factors associated with work related musculoskeletal disorders of the upper limbs (10 pts).

6) What are the design factors that need to be considered to determine the size of the characters on a sign to be installed in a work environment (5 pts)?

7) A machine operator must push on a lever with a force of 18 N. The lever is used every 5 minutes, but must be pushed for 30 seconds each time. The arm of the operator is at a 45° angle with the body when pushing on the lever. Determine if this situation is acceptable for a female worker with a 25th percentile shoulder flexion force taken from Table 1.15, page 68 of Kodak. (15 pts)

8) Workers are complaining about back and shoulder pain, which they associate to excessive weight of the loads that they must handle. These loads are lifted from a conveyor at 65 cm from the floor, to a hook at shoulder height. The loads are lifted 16 times per day (8 hours) and weigh 12.3 Kg.

   a) Using the NIOSH Manual Lifting Guidelines, determine the RWL for this task. (10 pts)
   b) Explain the hypothesis that you stated to obtain the answer in a). (5 pts)

   RWL (Kg) = 23 (HM) (VM) (DM) (AM) (CM) (FM)

   - HM (Horizontal Multiplier) = 25 / H where H = cm
   - VM (Vertical Multiplier) = (1 - (0.003 |V -75 |)) where V = cm
   - DM (Distance Multiplier) = (0.82 + 4.5 / D) where D = cm
   - AM (Asymmetry Multiplier) = (1 - (0. 0032 A)) where A = degrees

Appendix

Anthropometric data

TABLE 1–3. Body Dimensions of U.S. Civilian Adults, Female/Male, in mm

	Percentiles			
	5th	*50th*	*95th*	*SD*
HEIGHTS				
(*f* above floor, *s* above seat)				
Stature ("height")[f]	1,527.8/1,646.9	1,629.4/1,755.8	1,737.3/1,866.5	63.6/66.8
Eye height[f]	1,415.2/1,528.2	1,516.1/1,633.9	1,621.3/1,742.9	62.5/65.7
Shoulder (acromial) height[f]	1,240.9/1,341.6	1,333.6/1,442.5	1,432.0/1,545.6	57.9/62.0
Elbow height[f]	926.3/995.2	997.9/1,072.5	1,074.0/1,152.8	44.8/48.1
Wrist height[f]	727.9/777.9	790.3/846.5	855.1/915.2	38.6/41.5
Crotch height[f]	700.2/764.4	771.4/837.2	845.8/916.4	44.1/46.2
Height (sitting)[s]	795.3/854.5	852.0/913.9	910.2/971.9	34.9/35.6
Eye height (sitting)[s]	684.6/735.0	738.7/792.0	794.3/848.0	33.2/34.2
Shoulder (acromial) height (sitting)[s]	509.1/548.5	555.5/597.8	603.6/646.3	28.6/29.6
Elbow height (sitting)[s]	175.7/184.1	220.5/230.6	264.4/273.7	26.8/27.2
Thigh height (sitting)[s]	140.4/148.6	158.9/168.2	180.2/189.9	12.1/12.6
Knee height (sitting)[f]	474.0/514.4	515.4/558.8	560.2/605.7	26.3/27.9
Popliteal height (sitting)[f]	351.3/394.6	389.4/434.1	429.4/476.3	23.7/24.9
DEPTHS				
Forward reach (to tip of thumb)	676.7/739.2	734.6/800.8	796.7/867.0	36.4/39.2
Buttock–knee distance (sitting)	542.1/569.0	588.9/616.4	639.8/667.4	29.6/29.9
Buttock–popliteal distance (sitting)	440.0/458.1	481.7/500.4	527.7/545.5	26.6/26.6
Elbow–fingertip distance	406.2/447.9	442.9/484.0	482.5/524.2	23.4/23.3
Chest depth	208.6/209.6	239.4/243.2	277.8/280.4	21.1/21.5
BREADTHS				
Forearm–forearm breadth	414.7/477.4	468.5/546.1	528.4/620.6	34.7/43.6
Hip breadth (sitting)	342.5/328.7	384.5/366.8	432.2/411.6	27.2/25.2
HEAD DIMENSIONS				
Head circumference	522.5/542.7	546.2/567.7	570.5/593.5	14.6/15.4
Head breadth	136.6/143.1	144.4/151.7	152.7/160.8	4.9/5.4
Interpupillary breadth	56.6/58.8	62.3/64.7	68.5/71.0	3.6/3.7
FOOT DIMENSIONS				
Foot length	224.4/248.8	244.4/269.7	264.6/292.0	12.2/13.1
Foot breadth	81.6/92.3	89.7/100.6	97.8/109.5	4.9/5.3
Lateral malleolus height[f]	52.3/58.4	60.6/67.1	69.7/76.4	5.3/5.5
HAND DIMENSIONS				
Circumference, metacarpal	172.5/198.5	186.2/213.8	200.3/230.3	8.5/9.7
Hand length	165.0/178.7	180.5/193.8	196.9/210.6	9.7/9.8
Hand breadth, metacarpal	73.4/83.6	79.4/90.4	85.6/97.6	3.8/4.2
Thumb breadth, interphalangeal	18.6/21.9	20.7/24.1	22.9/26.5	1.3/1.4
WEIGHT (in kg)	39.2*/57.7*	62.0/78.5	84.8*/99.3*	13.8*/12.6*

*Estimated (from Kroemer 1981).

Source: Adapted from U.S. Army data reported by Gordon et al. (1989).

Note: In this table, the entries in the 50th-percentile column are actually mean (average) values. The 5th- and 95th-percentile values are from measured, not calculated, data (except for weight). Thus, the values given may be slightly different from those obtained by subtracting 1.65 SD from the mean (50th percentile) or by adding 1.65 SD to it.

Normal distribution table

[z = (x – mean) / standard-deviation]

p	z	p	z	p	z	p	z
1	*-2.33*	*26*	*-0.64*	*51*	*0.03*	*76*	*0.71*
2	*-2.05*	*27*	*-0.61*	*52*	*0.05*	*77*	*0.74*
3	*-1.88*	*28*	*-0.58*	*53*	*0.08*	*78*	*0.77*
4	*-1.75*	*29*	*-0.55*	*54*	*0.10*	*79*	*0.81*
5	*-1.64*	*30*	*-0.52*	*55*	*0.13*	*80*	*0.84*
6	*-1.55*	*31*	*-0.50*	*56*	*0.15*	*81*	*0.88*
7	*-1.48*	*32*	*-0.47*	*57*	*0.18*	*82*	*0.92*
8	*-1.41*	*33*	*-0.44*	*58*	*0.20*	*83*	*0.95*
9	*-1.34*	*34*	*-0.41*	*59*	*0.23*	*84*	*0.99*
10	*-1.28*	*35*	*-0.39*	*60*	*0.25*	*85*	*1.04*
11	*-1.23*	*36*	*-0.36*	*61*	*0.28*	*86*	*1.08*
12	*-1.18*	*37*	*-0.33*	*62*	*0.31*	*87*	*1.13*
13	*-1.13*	*38*	*-0.31*	*63*	*0.33*	*88*	*1.18*
14	*-1.08*	*39*	*-0.28*	*64*	*0.36*	*89*	*1.23*
15	*-1.04*	*40*	*-0.25*	*65*	*0.39*	*90*	*1.28*
16	*-0.99*	*41*	*-0.23*	*66*	*0.41*	*91*	*1.34*
17	*-0.95*	*42*	*-0.20*	*67*	*0.44*	*92*	*1.41*
18	*-0.92*	*43*	*-0.18*	*68*	*0.47*	*93*	*1.48*
19	*-0.88*	*44*	*-0.15*	*69*	*0.50*	*94*	*1.55*
20	*-0.84*	*45*	*-0.13*	*70*	*0.52*	*95*	*1.64*
21	*-0.81*	*46*	*-0.10*	*71*	*0.55*	*96*	*1.75*
22	*-0.77*	*47*	*-0.08*	*72*	*0.58*	*97*	*1.88*
23	*-0.74*	*48*	*-0.05*	*73*	*0.61*	*98*	*2.05*
24	*-0.71*	*49*	*-0.03*	*74*	*0.64*	*99*	*2.33*
25	*-0.67*	*50*	*0*	*75*	*0.67*		

TABLE 1.15
The Strength of Upper-Extremity Muscle Groups

Muscles	Gender	n	Newtons ± 1 SD	Pounds ±-1 SD	Torque Nm	Source
Isometric forearm flexion	M	436	276 ± 88	62 ± 20	70	Kamon and Goldfuss 1978
	M	74	336 ± 78	76 ± 18	85	Champney 1983
	F	136	160 ± 51	36 ± 12	38	Kamon and Goldfuss 1978
	F	18	174 ± 56	39 ± 13	41	Champney 1983
Isometric forearm extension	M	92	159 ± 29	36 ± 6	40	Tornvall 1963
	F	14	106	24	25	Kroll 1971
Dynamic forearm flexion—two hands	M	48	324 ± 46	73 ± 10	73	Kamon, Kiser and Landa-Pytel 1982
	F	—	168	38	40	
Isometric shoulder flexion—45 and 135°	M-45	62	124 ± 40	28 ± 9	62	Champney 1979
	M-135	9	95 ± 21	21 ± 5	48	Yates et al. 1980
	F-45	18	53 ± 22	12 ± 5	25	Champney 1979
	F-135	9	44 ± 14	10 ± 3	21	Yates et al. 1980

exhaustion or until the supervising medical personnel stopped the test. The measured values of aerobic capacity by age groups are shown in Table 1.19 were as follows (Pohjonen 2001):

The differences in the capacity tests and in the populations may explain the higher values for Finnish health care workers than for the industrial women in Table 1.20.

Another study using a maximal treadmill test showed women's aerobic capacities to range from 25.7 ± 3.0 ml O_2 per kg of body weight per minute in 33 women from 50 to 59 years to 26.9 ± 4.0 for 47 women from 40 to 49 years and to 29.1 ± 3.5 for 39 women from 29 to 39 years (Profant et al. 1972). These values are similar to the ones based on the submaximal treadmill studies presented in Table 1.20.

The predicted maximum aerobic capacities for the population of industrial workers shown above can be illustrated on a cumulative frequency distribution. From this one can estimate what percentage of the mixed male and female workforce would have the capacity needed to perform tasks of different effort levels for varying times during a work shift. The distribution is shown in Figure 1.21 with lines drawn to show where the 5th, 20th, 50th, 80th, and 95th percentiles for whole-body aerobic capacity would fall. The use of this data has been discussed earlier in this chapter; additional discussion of this use of whole-body capacity data can be found in Chapter 6 and in the first edition of this book, Volume 2.

TABLE 1.16
Maximum Torque Values for the Forearm and Wrist in Men and Women (Asmussen and Heebol-Nielsen 1961)

To get the torque values for Table 1.16, it was assumed that the forearm lengths for men and women were 0.254 m and 0.238 m, respectively. Moment arms assumed for the torque estimates were 0.5 m for men and 0.48 for women (Kamon et al. 1982).

Joint Motion	Sex	n	Nm ± 1 SD
Isometric wrist flexion	M	96	8.0 ± 1.8
	F	81	5.5 ± 0.9
Isometric wrist extension	M	96	10.1 ± 2.2
	F	81	6.9 ± 1.2
Isometric forearm pronation			
Handle	M	96	14.1 ± 3.1
	F	81	8.6 ± 1.6
Key	M	96	4.1 ± 0.6
	F	81	3.2 ± 0.5
Isometric forearm supination			
Handle	M	96	15.0 ± 2.7
	F	81	8.6 ± 1.5
Key	M	96	4.2 ± 0.7
	F	81	3.3 ± 0.5

TABLE 1.17
Maximum Isometric Pull Strengths (Newtons ± 1 SD) on a Tray (Champney 1979; Yates et al. 1980)

The bold figures show data points where 18 women and 37 men were included. The other values are based on 9 women and 9 men in a university setting. The additional people studied were industrial workers.

Height Above Floor in cm (in.)	Horizontal Distance 18 (7)	Horizontal Distance 36 (14)	Horizontal Distance 51 (20)
188 (74) M	177 ± 59	169 ± 44	122 ± 26
134 (53) M	293 ± 77	253 ± 93	182 ± 69
81 (32) M	607 ± 158	323 ± 96	251 ± 30
33 (13) M	744 ± 221	540 ± 144	302 ± 91
170 (70) F	66 ± 34	54 ± 23	41 ± 17
134 (53) F	104 ± 58	115 ± 39	92 ± 41
81 (32) F	338 ± 146	184 ± 80	118 ± 45
33 (13) F	430 ± 190	248 ± 50	131 ± 36