Predicting Upper Limb Discomfort for Plastic Surgeons: combining anthropometric models with Rapid Upper Limb Assessment (RULA)

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Abstract. Plastic surgeons report neck, shoulder and back pain after wearing loupes during operations. This research aimed to discover the inter-relation between factors leading to upper-limb discomfort e.g. viewing angle, stature, or height at which the operation is performed. Ten postures are simulated using digital human models. We then apply multi-objective optimization to characterize the posture of the surgeon in relation to musculoskeletal risk (defined using RULA). It is possible to predict RULA scores for the range of postures. This could be used to quantify risk assessment, particularly in the selection and fitting of loupes and the specification of working height for surgery. Adjusting the operating height could decrease neck flexion angle and reduce musculoskeletal risk.

Keywords. Plastic surgeon, Loupes, Multi-Objective Optimization, RULA.

1. Introduction

Plastic surgeons report a high incidence of musculoskeletal injuries, with neck pain being the most commonly reported condition (Capone et al., 2010). A key factor would appear to be the visual aids used by surgeons, such as loupes or microscopes. Surgeons who routinely use loupes are at the increased risk of neck Musculoskeletal Disorder (Sivak-Callcott et al., 2011). Surgical loupes consist of magnifying lenses mounted on glasses. Each pair of loupes are custom-fitted for an individual surgeon based on two factors: the working distance and the declination angle (Chang, 2014). The declination angle is the angle between a reference line (from the top of the ear to the corner of the eye) and the optical axis of loupes. Through-the-lens (TTL) loupes have declination angles of between 20-25°. Because of the difference between viewing and working distances, flexion of the neck could increase as the surgeon adjusts their posture. In this paper, the relationship between surgeon stature (SS) and table height (TH, the vertical distance from the patient's operation position to the floor) will be analyzed. In a study of experienced surgeons performing discectomy (on a spine surgery simulator) when wearing loupes, it is proposed that a table height midway between the umbilicus and sternum are optimal for reducing surgeon musculoskeletal fatigue (Park et al., 2012).

2. Methods

In this paper, we employ a combination of digital anthropometric model, Multi-Objective Optimization and RULA. In figure 1, S_b is the neck and trunk scores, defined using RULA, which we are seeking to minimize. Based on the UK PEOPLE SIZE 1998 database, 10 digital human models are built. Multi-Objective Optimization is used to predict the optimal posture of surgeon in order to define the minimum S_b. This process allows us to calculate the relationship between SS and TH.

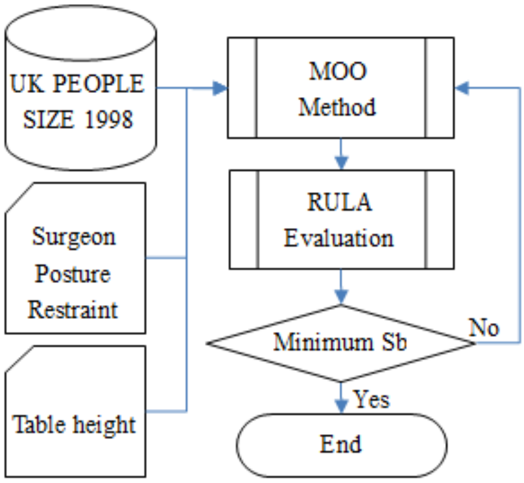


Figure 1 Data processing flow chart

2.1 Digital Anthropometric models

A digital anthropometric model is used to define the posture that a surgeon will adopt during an operation. This model was based on motion capture and observation studies conducted in our laboratory (involving 3 experienced plastic surgeons performing simulated tasks). In order to simplify the model, a 2-dimensional link model is built (Figure 2).

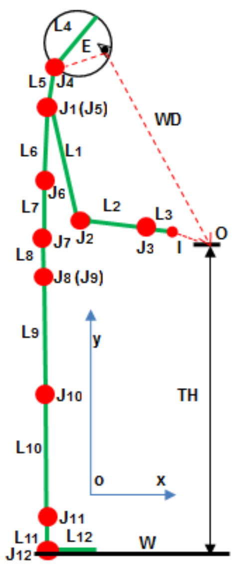


Figure 2 2-D structure and link constraint

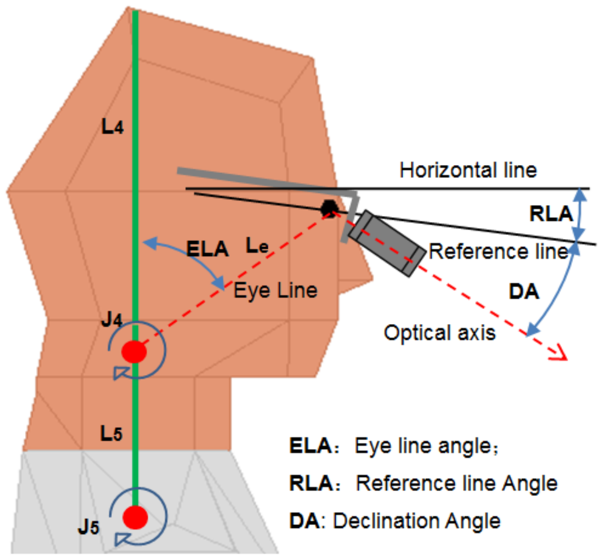


Figure 3 Neck and Head link diagram

O: Operation position; I: Instrument; E: Eye line: The line connects the head joint and eye; WD: Distance from eye to operation position; TH: Height of the operation position; W: x-coordinate of operation field.

In Figure 2, each joint has a local coordinate and the y axis is in line with the link. Figure 3 shows the model of a head wearing loupes. We assume a Declination Angle

(DA) of 25°. The Reference Line Angle (RLA) is taken as 12° (Chang, 2014). The Eye Line Angle (ELA), defined with reference to a line connecting the head joint (J_4) and the eye, is defined as the angle between the eye line and the head link (L_4) and is set at 45°.

The models are defined using standing height of adults from 5% female to 95% male based on UK PEOPLE SIZE 1998(Freer et al., 2008). Table 1 lists the body data for female and male models at 10%ile intervals: 5%, 25%, 50%, 75% and 95%.

Table 1 Stature and link length of digital human (mm)

Human Model	Stature	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}
F_5 (5% Female)	1534	258	234	159	205	136	161	160	81	390	334	67
F_{25} (25% Female)	1596	274	245	169	207	138	171	170	86	409	347	68
F_{50} (50% Female)	1634	285	253	175	208	139	177	176	89	422	355	68
F_{75} (75% Female)	1672	296	261	181	209	140	183	182	92	435	363	68
F_{95} (95% Female)	1734	312	272	191	211	142	193	192	90	454	376	75
M_5 (5% Male)	1652	293	265	174	216	142	173	176	80	410	383	72
M_{25} (25% Male)	1715	309	276	184	218	144	184	186	85	427	397	74
M_{50} (50% Male)	1758	319	283	190	220	146	191	192	88	439	407	75
M_{75} (75% Male)	1801	329	290	196	222	148	198	198	91	451	417	76
M_{95} (95% Male)	1864	345	301	206	224	150	209	208	96	468	431	78

Joint angle limits for the body are determined based using the SAMMIE system (Freer et al., 2008), and some joint angle limits are defined by the working posture of surgeons (Chang, 2014; Steinhilber et al., 2015). We assume that some joints do not contribute significantly to postural variability during the course of an operation, and so these can be frozen in the model. The frozen joints are the hip joint (J_8), thigh joint (J_9), leg joint (J_{10}), ankle joint (J_{11}) and foot joint (J_{12}). Thus, 7 active joints (J_1 to J_7) are used for the standing model. x_n represents the angle of each joint. Joint angle limits are listed in Table 2.

Table 2 Joint angle limits (degree)

Joint	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}	J_{11}	J_{12}
Angle	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
Lower	-5	-1	-65	0	0	0	0	0	0	0	0	0
Upper	20	145	70	10	50	5	5	0	0	0	0	0

We assume that the surgeon will hold surgical instruments, which provide a focal point for their vision. Table 3 shows the corresponding dimensions of scissors (Length: 140mm) and forceps (Length: 120mm). We define the valid length of instruments is $l_t = 70$ mm, the angle between y axis and instrument is $x_t = 120°$.

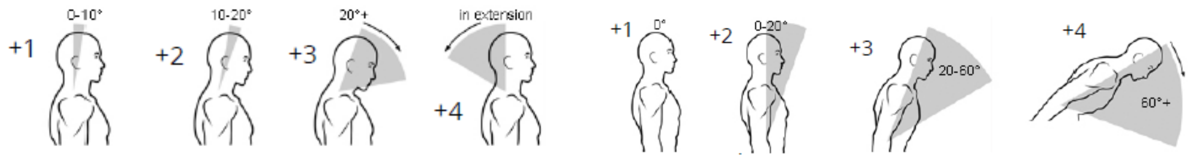
Table 3 other length and angle variants

Define	Length (mm)	Angle (degree)
Vision	$l_v \in \{380,400,420,\cdots,760\}$	$x_v = 90 + RLA + DA = 127°$
Eye position	$l_e = l_4 * 0.63$	$x_e = ELA = 45°$
Instrument	$l_t = 140/2 = 70$	$x_t = 120°$
Operation field	$l_h \in \{800,850,900,\cdots,1250\}$	$x_h = 180°$

2.2 The RULA method

RULA is a survey method for upper limb disorders (McAtamney & Coreltt, 1993). RULA supports classification of posture in terms of potential musculoskeletal risk through a simple pencil and paper pro forma. We are interested in relating this classification scheme to the postures defined by the anthropometric model.

In RULA, there are three score tables. Table B describes risks associated with neck and trunk angle. Since neck discomfort is the most common disorder reported by surgeons, we apply Table B in this project. The score of Table B is defined as S_b (table 4). In order to analyze the continuously changing angles of neck and trunk, two functions (Equation (1) and Equation (2)) were created according to Figure 4 (a) and Figure 4 (b).



(a) Neck angle *(b) Trunk angle*

Figure 4: The posture scores for body part the neck and trunk (Middlesworth, 2015)

$$S_n = F_1(x) = -0.0008x^2 + 0.0987x + 1.094 \quad (1)$$
$$S_t = F_2(x) = -0.0002x^2 + 0.0424x + 1.076 \quad (2)$$

In Equation (1), S_n is the (RULA) score of neck angle. In Equation (2), S_t is the score of trunk angle. x is the joint angle. Using table 2, we defined these joint angles as: Equation (1), $x = x_4 + x_5$; Equation (2), $x = x_6 + x_7$.

In order to more precisely defineS_b, a surface grid (as shown Figure 5) was created based on Table 4 and Equation (3).

$$S_b = F(S_n, S_t) \quad (3)$$

Table 4 RULA scores for neck and trunk

Table B						
Score Neck Posture	Trunk Posture Score					
	1	2	3	4	5	6
1	1	2	3	5	6	7
2	2	2	4	5	6	7
3	3	3	4	5	6	7
4	5	5	6	7	7	8
5	7	7	7	8	8	8
6	8	8	8	8	9	9

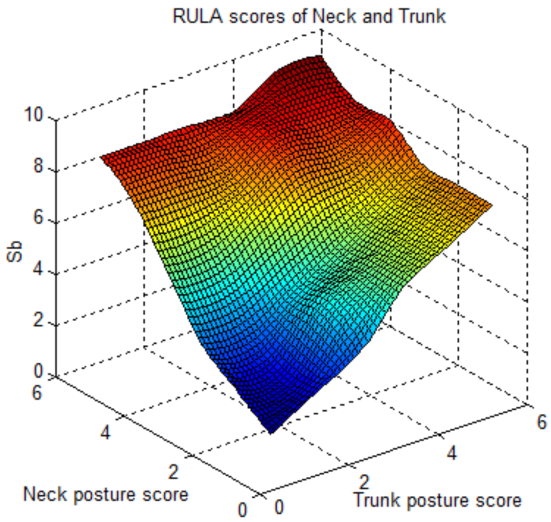


Figure 5: Surface grid of S_b

2.3 Multi-objective optimization

Multi-objective optimization is the process of optimizing an outcome variable by systematically and simultaneously adjusting a collection of objective functions. This approach has been used to predict human posture (Yang et al., 2010; Gagg et al., 2012) . In this paper, S_b is used as the outcome variable. The optimization problem is defined as follows:

Find: $x = [x_1 \ x_2 \ \cdots \ x_{12}]$ (4)

Minimize $\underset{x}{} F(x) = S_b = F[F_1(x), F_2(x)]$ (5)

Subject to:

$h_1 = abs(l_6 * \cos(x_7 + x_6) + l_7 * \cos x_7 + l_8 + l_9 + l_{10} + l_{11}) - abs(l_5 * \cos(x_7 + x_6 + x_5) + l_e * \cos(x_7 + x_6 + x_5 + x_4 + x_e) + l_v * \cos(x_7 + x_6 + x_5 + x_4 + x_v) + l_h)$
(6)

$h_2 = abs\big(l_1 * \cos(180 - x_1) + l_2 * \cos\big(180 - (x_1 + x_2)\big) + l_3 * \cos\big(180 - (x_1 + x_2)\big) + l_t * \cos x_t\big) - abs(l_5 * \cos(x_7 + x_6 + x_5) + l_v * \cos(x_7 + x_6 + x_5 + x_4 + x_v) + l_e * \cos(x_7 + x_6 + x_5 + x_4 + x_e))$ (7)

$h_3 = abs\big(l_1 * \sin(180 - x_1) + l_2 * \sin\big(180 - (x_1 + x_2)\big) + l_3 * \sin\big(180 - (x_1 + x_2)\big) + l_t * \sin x_t\big) - abs(l_5 * \sin(x_7 + x_6 + x_5) + l_v * \sin(x_7 + x_6 + x_5 + x_4 + x_v) + l_e * \sin(x_7 + x_6 + x_5 + x_4 + x_e))$ (8)

$h_4 = x_3 - x_2$ (9)

$g_1 = x_1 - x_6$ (10)

$x_i^L \leq x_i \leq x_i^U$ (11)

Equation (6~11) define constraints for the model: h_1 is the vision constraint allowing standing surgeon to see clearly the instruments; l_h is equal to TH; h_2 and h_3 define hand position. Based on those constraints, the digital anthropometric model can see and reach the instruments on the patient at a working distance and declination angle which is constrained by the viewing angle of the loupes; h_4 ensures that hand is in line with the lower arm; g_1 ensures the upper arm maintains a small angle. Based on the surgeon standing posture, x_i are limited within the upper and lower values.

3. Results and Discussion

10 different percentile digital human models were analyzed. The stature range is from 1534mm to 1864mm. Table height is from 800mm to 1250mm (increment is 50mm). Results are listed in Table 5.

Table 5 S_b scores as wearing 25 degree loupes

Table Height (TH)	Surgeon Stature(SS)									
	F-5	F-25	F-50	M-5	F-75	M-25	F-95	M-50	M-75	M-95
	1534	1596	1634	1652	1672	1715	1734	1758	1801	1864
1250	-	-	-	-	-	-	-	-	2.18	2.27
1200	-	-	-	-	-	-	-	2.35	2.35	2.44
1150	-	2.18	2.35	2.27	2.27	2.27	2.35	2.35	2.44	2.44
1100	2.27	2.27	2.27	2.35	2.27	2.35	2.27	2.53	2.46	2.74
1050	2.35	2.44	2.35	2.44	2.53	2.63	2.63	2.63	2.86	3
1000	2.46	2.53	2.63	2.46	2.74	2.74	2.56	2.51	3	3.16
950	2.63	2.86	2.56	3	3	3	3.16	3.16	3.53	3.73
900	2.86	3.16	3.34	3.34	3.34	3.53	3.53	3.53	3.73	4.15
850	3.34	3.53	3.53	3.53	3.94	3.94	3.94	4.15	4.15	4.8
800	3.53	4.15	4.15	3.94	4.11	4.15	4.29	4.29	4.29	4.96

Table 5 shows the association between S_b, SS and TH. The top zone, with the '-' symbol, indicates no solution. The next zone, has $2 \le S_b < 3$. Below this, S_b is $3 \le S_b < 4$. Finally, at the bottom of table 5, $S_b \ge 4$.
(1) $TH \in \{1200,1250\}$, Stature ≤95% female and < 50% male do not have a solution.
(2) $TH \in \{1050,1100,1150\}$, ≤ 5% female does not have a solution as TH=1150mm. In other conditions, $S_b < 3$. Trunk and neck is in negligible risk (McAtamney & Corlett, 1993). When TH is between 1050mm and1150mm, 93% populations lie in the green zone. So this range of table height is recommended.
(3) In second from bottom zone, most of TH is TH$\in \{850,900,950\}$. The table height is low in relation to for most of male and female. For example, when TH=950mm, S_b of all male are larger than 3. Trunk and neck is in low risk (McAtamney & Corlett, 1993).
(4) In the bottom zone, most of TH is TH$\in \{800,850\}$. Surgeons whose stature is bigger than 50% male's are all in the risk. This table height should be avoided.

4. Conclusion

In this paper, table height is the operation position height, and it is a reference value for adjusting the table. The position of the patient should be considered.
The study shows how RULA scores change for different table heights depending on the stature of surgeon. RULA is a useful assessment value for surgeon posture prediction. The result shows that reasonable table height of for surgeon could decrease the flexion angle of neck.

References

Capone, A. C., Parikh, P. M., Gatti, M. E., Davidson, B. J., et al. (2010). Occupational injury in plastic surgeons. Plast Reconstr Surg, 125(5), 1555-1561.

Chang, B. (2014). Key Factors for Ordering Customer Loupes, Part 1: Declination Angle as the Key Ergonomic Factor., Retrieved July. 5, 2015. from http://archive.constantcontact.com/fs113/1113715421610/archive/1117208896207.html.

Freer, M., Marshall, R., & Summerskill, S. (2008). Manual for SAMMIE System v8.3: SAMMIE CAD Ltd.

Gagg, J., Yang, J., & Howard, B. (2012). Hybrid method for driver accommodation using optimization-based digital human models. Computer-Aided Design, 44, 29-39.

McAtamney, L., & Corlett, E. N. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon, 24(2), 91-99.

Middlesworth, M. (2015). Rapid Upper Limb Assessment (RULA). Retrieved July. 5, 2015. from http://ergo-plus.com/rula-assessment-tool-guide/

Park, J. Y., Kim, K. H., Kuh, S. U., Chin, D. K., et al. (2012). Spine surgeon's kinematics during discectomy according to operating table height and the methods to visualize the surgical field. Eur Spine J, 21(12), 2704-2712.

Sivak-Callcott, J. A., Diaz, S. R., Ducatman, A. M., Rosen, C. L., et al. (2011). A Survey Study of Occupational Pain and Injury in Ophthalmic Plastic Surgeons. Ophthalmic Plastic & Reconstructive Surgery, 27(1), 28.

Steinhilber, B., Hoffmann, S., Karlovic, K., Pfeffer, S., et al. (2015). Development of an arm support system to improve ergonomics in laparoscopic surgery: study design and provisional results. Surg Endosc, 29(9), 2851-2858.

Yang, J., Marler, T., & Rahmatalla, S. (2010). Multi-objective optimization-based method for kinematic posture prediction: development and validation. Robotica, 29(02), 245-253.