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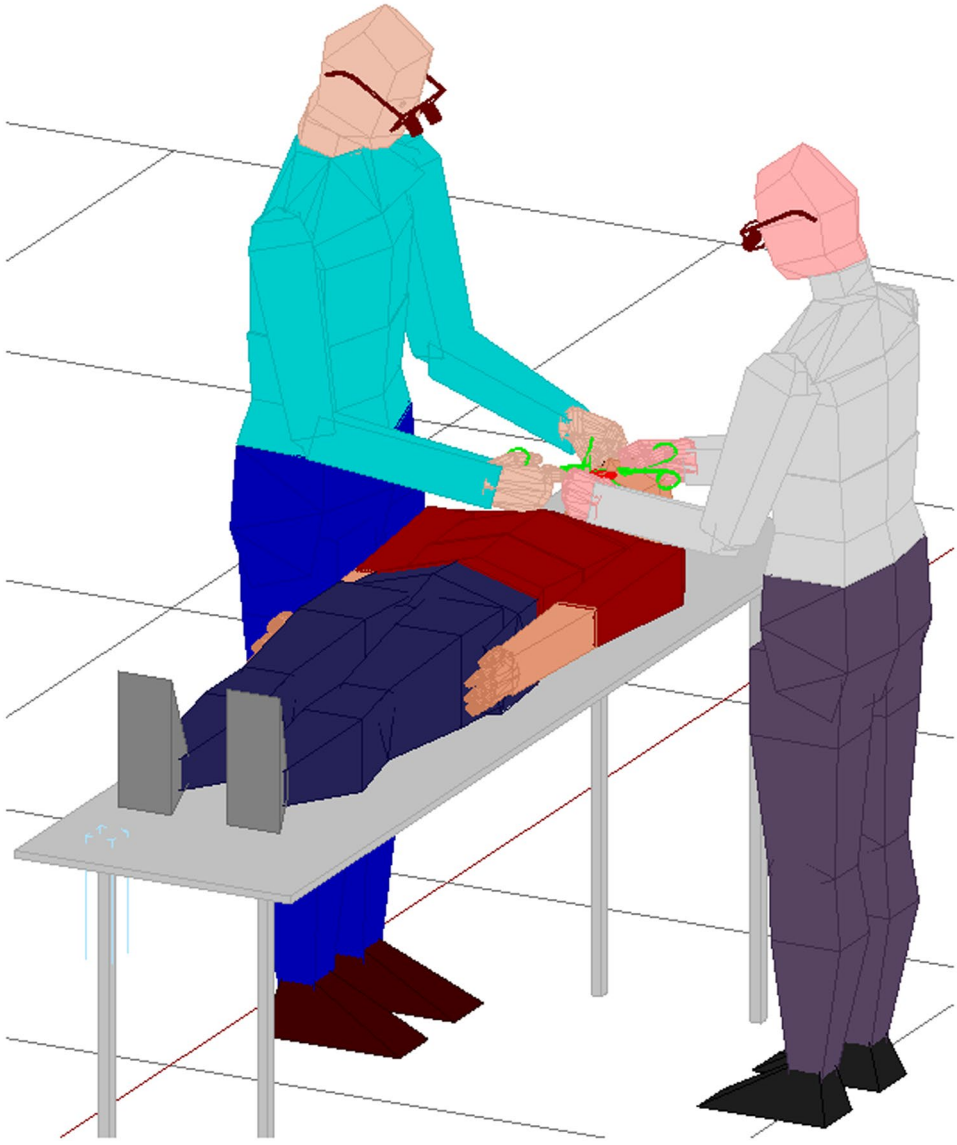

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Predicting upper limb discomfort for plastic surgeons wearing loupes based on multi-objective optimization

Zhelin Li[1,2,*], Chris Baber[2], Francois-Xavier Li[3], Christopher Macdonald[4] and Yvette Godwin[5]

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Abstract: Plastic surgeons report neck, shoulder and back pain when wearing head-mounted magnifiers (loupes) during operations. There will be many factors contributing to such pain. In order to explore these factors this paper developed a novel application of Multi-objective Optimization (MOO) which used postural constraints on anthropometric models to determine Rapid Upper Limb Analysis (RULA) scores. For the pain experienced by surgeons wearing loupes, the analyses showed that adjusting the height of table and suitable working distance of loupes for surgeon could decrease the flexion angle of neck. The results demonstrated that it is possible to predict RULA scores for the range of postures and propose that this approach could be used to quantify risk assessment, particularly in the selection and fitting of loupes and in the specification of working height for surgeons.

Subjects: Ergonomics & Human Factors; Musculosketletal Disorders - Ergonomics; Plastic & Esthetic Surgery

Keywords: plastic surgeon; loupes; multi-objective optimization; RULA

1. Introduction

Plastic surgery involves a range of specialisms directed at the reconstruction or correction of dysfunctional or defective parts of the body. Given the nature of the work (particularly when working on children or on the hand), it is common for plastic surgeons to employ some form of visual aids, such as microscopes or head-mounted magnifying glasses called loupes. While these visual aids can enhance surgeons' vision, there can be a need to adopt uncomfortable postures during an operation

Zhelin Li

ABOUT THE AUTHOR

Zhelin Li is a professor in the Design School of South China University of Technology. He is the director of the Laboratory Center at SCUT School of Design. His research fields are ergonomics evaluation of products, digital human modeling, new interface technology and interactive products design. His research projects include ergonomics analysis of head-mounted product, human-machine interface techniques, development of control software in recent years. He was a visiting research fellow in the School of Engineering, Birmingham University UK in 2015. The research topic is about plastic surgeons during surgery and define possible postures that may contribute to cervical musculoskeletal disorders by using ergonomic methods (motion capture techniques) when he was in UK.

PUBLIC INTEREST STATEMENT

Plastic surgeons report neck, shoulder and back pain when wearing head-mounted magnifiers (loupes) during operations. There will be many factors contributing to such pain. In order to explore these factors this paper developed a novel application of Multi-objective Optimization which used postural constraints on anthropometric models to determine Rapid Upper Limb Analysis scores. For surgeons wearing loupes, the analyses showed that adjusting the height of table and suitable working distance of loupes for surgeon could decrease the flexion angle of neck. The approach is applied to the surgeons who wear head-mounted magnifiers and report a neck injury.

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in order to see the operating site while performing action on that site. Not surprisingly, therefore, plastic surgeons who wear loupes during surgery report a high incidence of musculoskeletal injuries (Capone, Parikh, Gatti, Davidson, & Davison, 2010; Nimbarte, Zreiqat, & Chapman, 2012). A survey of European surgeons reported more than 80% (n = 284) had discomfort in the neck, shoulder and back muscles associated with operating (Wauben, van Veelen, Gossot, & Goossens, 2006). Sivak-Callcott reported 58% of ophthalmic plastic surgeons (n = 139) had neck pain associated with operating. Nearly 10% had to cease operating as a result of neck pain (Sivak-Callcott et al., 2011). In a recent survey, authors identified contributory factors as the age of the respondent (older respondents were more likely to report pain), the number of hours operating while wearing loupes (more than 15 h per week performing operations led to higher incidence of pain), and the magnification of the loupes (higher magnification of loupes resulted in more reports of symptoms). While the first two factors could be seen as self-explanatory, it is worth considering the third and why this relates the design of the loupes.

Surgical loupes consist of magnifying lenses mounted on prescription spectacles. Loupes are custom-fitted for an individual surgeon based on two factors: the working distance and the declination angle (Chang, 2014). The working distance is influenced by the magnification of the loupes; ranging from around 2x to 5x. For some procedures, there is a recommendation to use 2.5x (1, 2). In our survey, 23% of respondents used 2.5x while 67% used 3.5x (the remainder using 2x, 3x or 4x). The magnification will influence the size of the visual field that can be seen clearly at a given viewing distance, e.g. higher magnification loupes of 4x or 5x will have a smaller visual field in sharp magnification (and might be used for vascular surgery for instance). Loupes have specified viewing distances (ranging from 34 to 50 cm) which are intended to be distances at which images are clear. However, viewing distance will also be influenced by the stature of the surgeon and the working height of the operation. Consequently, wearing loupes creates the need to trade-off the loupe's viewing distance (for a clear image) and the surgeon's working distance (to gain access to the patient). Because of the limitation of viewing direction and working distance, the flexion angle of the neck could increase as the surgeon adjusts their posture during an operation.

A our preliminary study, using Vicon Motion Capture compared postures for four experienced surgeons performing simple tasks with and without loupes, while sitting or standing, and at different operating heights, as shown in Figure 1. From the analysis of surgeon posture, it was found that angles of neck and head were bigger as surgeon with loupes than without loupes on different height table. This indicated how differences in head and neck angle result from wearing loupes, and that these differences vary with the height of the table on which the task was performed.

In this paper, the relationship between surgeon stature (*SS*), working distance of loupes (*WD*, the distance from surgeon's eye to the patient's operation position) and table height (*TH*, the vertical distance from the patient's operation position to the floor) will be analyzed. The definition of working distance varies across specialisms and types of operation; some surgeons (particularly those operating on hands or feet) might prefer to remain seated during an operation, whereas surgeons performing other types of operation might prefer to stand. From initial discussion with surgeons it is noted that loupes are often fitted when the surgeon is seated and the viewing distance based on this. This suggests potential problems when moving from sitting to standing. In this paper, author focus on standing surgeons.

2. Methods

In this paper, author employ MOO method combining digital anthropometric modelling, and RULA. Figure 2 illustrates the approach taken in this paper.

Figure 1. The impact on the surgeon's posture of operating with loupes magnification: Lateral views recorded by Vicon Motion Capture whilst performing a manual tasks: (a) The head is held in the "Head forward position" while performing a simple task with loupes. The neck is in anterior flexion. The head is in a protracted position anterior to that of neutral posture: (b) Performing the same tasks without loupes decreases neck flexion and the "Head forward posture".

2.1. Digital anthropometric models

A digital anthropometric model is used in this approach to define the working posture in terms of the parameters which can be optimized. In order to simplify the model, a 2-dimensional body-link model is built based on the joints and links, as shown in Figure 3.

In Figure 3(a), each joint has a local coordinate (Y axis perpendicular to the floor, X axis in line with the floor). The height of table (*TH*) is set midway between the umbilicus and sternum. In a study of experienced surgeons performing discectomy (on a spine surgery simulator) when wearing loupes, it is proposed that this table height is optimal for reducing surgeon musculoskeletal fatigue (Park et al., 2012). The working distance (*WD*) is defined by the dotted line linking the operating position (O) being worked on using instrument (I) and the eye (E).

Figure 3(b) shows the model of the head wearing loupes. This has a reference line connecting the top of the ears to the corner of the eyes. The Reference Line Angle (*RLA*) is the deviation from a horizontal line from the top of the ears and is taken as 12° (Chang, 2014). The declination angle for the loupes is the angle between the reference line and the optical axis of loupes. Through-the-lens (*TTL*)

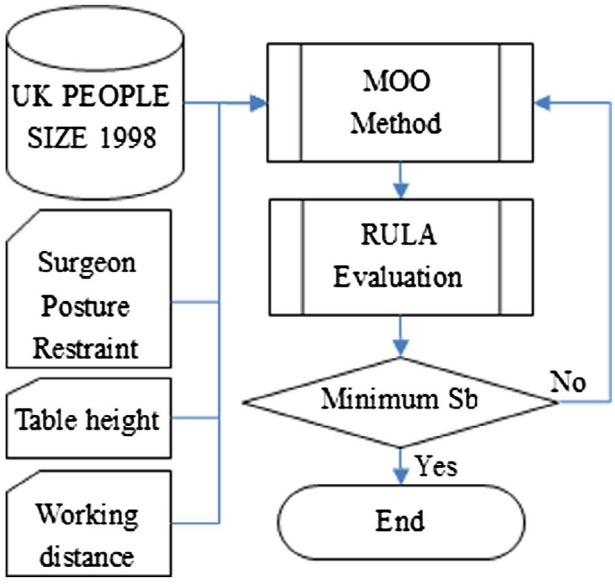

Figure 2. Data processing flow chart.

Notes: Sb refers to the Scores from (specifically neck and trunk scores) RULA Table B. Based on the UK PEOPLE SIZE 1998 database, 10 digital anthropometric models were built. Multi-Objective Optimization is used to predict the posture which minimizes RULA score, defined as minimum Sb, of a surgeon based on joint restraint in an digital anthropometric model.

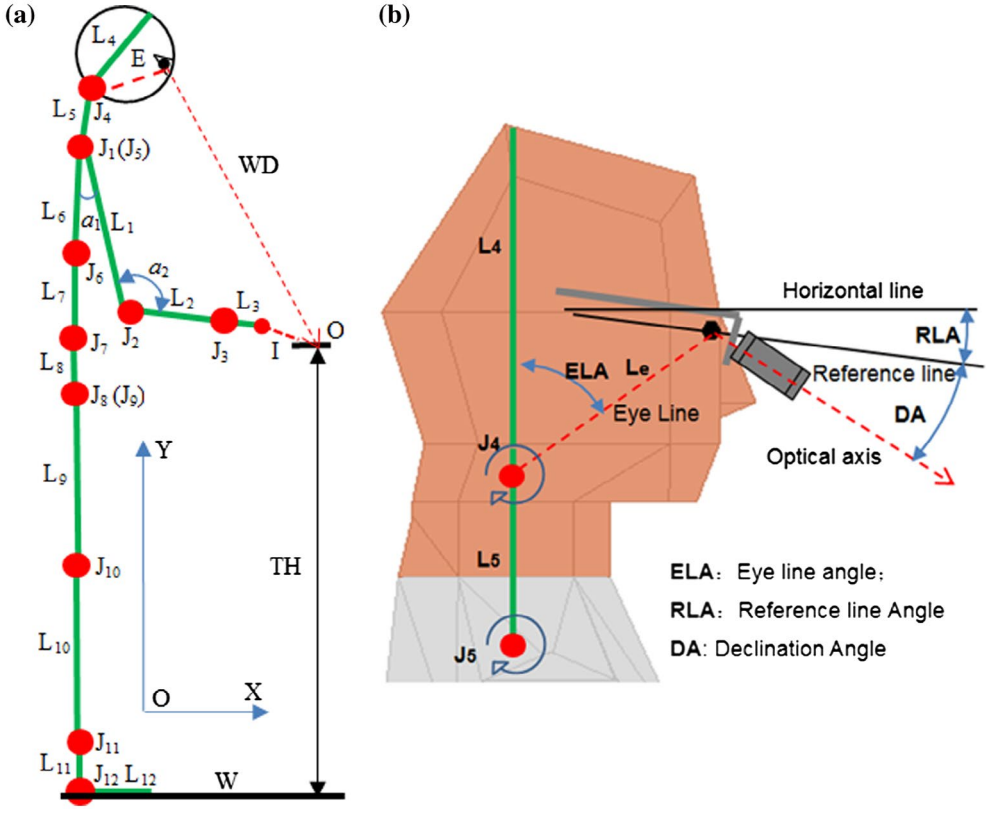

Figure 3. Operation position; I: Instrument; E: Eye line: The line connects the head joint and eye; WD: Working distance of loupes; TH: Table height; W: x-coordinate of operation field: (a) 2-D structure and link constraint. (b) Neck and Head link diagram.

loupes have declination angles of between 20 and 25°; a Declination Angle (*DA*) of 25° is assumed. 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°.

Joint angle limits are defined by the working posture of surgeons (Chang, 2014; Damodaran, Lee, & Lee, 2013; Park et al., 2014; Steinhilber et al., 2015), and determined using the SAMMIE system

Table 1. 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	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{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

Table 2. Other length and angle variants

Define	Length (mm)	Angle (degrees)
Table height	$l_h \in \{800, 850, 900, ..., 1{,}250\}$	$a_h = 180°$
Working distance	$l_v \in \{380, 400, 4{,}210, ..., 760\}$	$a_v = 90 + RLA + DA = 127°$
Eye position	$l_e = l_4 \times 0.63$	$a_e = ELA = 45°$
Instrument	$l_t = 140/2 = 70$	$a_t = 120°$

(Freer, Marshall, & Summerskill, 2008). In order to reduce model complexity, author 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}). This assumes that postural change happens from the waist upwards, and this paper are particularly interested in the extension and flexion of the neck during an operation. Thus, 7 active joints (J_1–J_7) are used for the standing model. a_i represents the joint angle between L_{i-1} and L_i, as shown in Figure 3. Joint angle limits for each degree of freedom are listed in Table 1.

In this study it is assumed that the surgeon will also work with surgical instruments, which provide a focal point for their vision with reference their hand position. Table 2 shows the corresponding dimensions of scissors (Item: MB150R, Length: 140 mm) (Aesculap, Inc, 2008). It is assumed that half of length of instrument is in the hand, so the valid length of instruments is $l_t = 70$ mm. It is defined that the angle between Y axis and instrument is $a_t = 120°$.

In order to accommodate a wide range of the surgeons' stature, ten digital human models are defined in terms of standing height of adults from 5% female up to 95% male (stature) based on UK PEOPLE SIZE 1998 (Freer et al., 2008). The stature range is from 1,534 to 1,864 mm. Table 3 lists the body data for female and male models at 20 or 25 percentile intervals: 5, 25, 50, 75 and 95%.

Table 3. Stature and link length of digital human (mm)

Human model	F_5	F_{25}	F_{50}	M_5	F_{75}	M_{25}	F_{95}	M_{50}	M_{75}	M_{95}
Stature	1,534	1,596	1,634	1,652	1,672	1,715	1,734	1,758	1,801	1,864
L_1	258	274	285	293	296	309	312	319	329	345
L_2	234	245	253	265	261	276	272	283	290	301
L_3	159	169	175	174	181	184	191	190	196	206
L_4	205	207	208	216	209	218	211	220	222	224
L_5	136	138	139	142	140	144	142	146	148	150
L_6	161	171	177	173	183	184	193	191	198	209
L_7	160	170	176	176	182	186	192	192	198	208
L_8	81	86	89	80	92	85	90	88	91	96
L_9	390	409	422	410	435	427	454	439	451	468
L_{10}	334	347	355	383	363	397	376	407	417	431
L_{11}	67	68	68	72	68	74	75	75	76	78

In Table 3, F_{25} means the 25% female, and M_{25} means the 25% male, and so on. One column in Table 3 represents the stature and length of links. For example, in the 3th column, stature = 1,596 and L_1 = 274 mean that the stature of F_{25} is 1,596 mm and length of upper arm is 274 mm (Figure 3(a) shows the position of L_1).

2.2. The RULA method

RULA is a popular tool to evaluate risk of musculoskeletal injury is called (McAtamney & Coreltt, 1993). RULA supports classification of posture in terms of potential musculoskeletal risk through a simple pencil and paper pro-forma. This can be completed from observation (either directly in the field or from video recordings) and can provide a consistent and reliable identification of postures which could be harmful. For this paper, authors are interested whether it is possible to use RULA predictively, i.e. as a means of identifying postural problems from models rather than observation. In this respect, this paper follow the lead of Plantard who captured human posture using the Microsoft KINECT sensor and derived corresponding RULA scores for a large set of poses and sensor placements (Plantard, Auvinet, Pierres, & Multon, 2015). Authors are interested in relating the RULA classification scheme to the postures defined by an anthropometric model. A core problem that needs to be solved prior to implementing such an approach is the need to determine which parameters are most significant in contributing to musculoskeletal risk classified by RULA. As there are multiple parameters which can contribute to risk, this requires the solution of a multi-objective problem.

In the RULA method, 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 plastic surgeons, this paper employ Table B (McAtamney & Coreltt, 1993). The score of Table B is defined as S_b. In order to analyse the continuously changing angles of neck and trunk, two functions—Equations (1) and (2)—were created by using quadratic fit of the RULA score and specific joint angles, according to studies by McAtamney and Coreltt (1993). In order to obtain a more precise definition of S_b, Equation (3) was created by using liner fit based on Table B.

$$S_n = F_1(a_{ne}) = -0.0008a_{ne}^2 + 0.0987a_{ne} + 1.094 \tag{1}$$

$$S_t = F_2(a_{tr}) = -0.0002a_{tr}^2 + 0.0424a_{tr} + 1.076 \tag{2}$$

$$S_b = F(S_n, S_t) \tag{3}$$

In Equation (1), S_n is the score for neck angle, and a_{ne} is the angle of neck. In Equation (2), S_t is the score for trunk angle, and a_{tr} is the angle of trunk. For consistency with SAMMIE, author defined these joint angles as: $a_{ne} = a_4 + a_5$; $a_{tr} = a_6 + a_7$.

2.3. Multi-objective optimization

The process of systematically and simultaneously optimizing a set of objective functions is called Multi-Objective Optimization (Marler & Arora, 2004). In general, a multi-objective optimization problem can be posed as follows:

(a) Minimize Function F of (x):

$$F(x) = \left[F_1(x), F_2(x), \cdots, F_k(x)\right]$$

where k is the number of objective functions.

(b) Subject to constraints defined as:

$$g_j(x) \le 0, j = 1, 2, \cdots, m;$$

$$h_l(x) = 0, l = 1, 2, \cdots, e;$$

where m is the number of inequality constraints, and e is the number of equality constraints.

$x \in E^n$ is a vector of design variables, where n is the number of independent variables x_i. $F(x) \in E^k$ is a vector of objective (or cost) functions $F_i(x)$: $E^n \to E^1$. x_i^* is the point that minimizes the objective function $F_i(x)$. The feasible design space X (often called the constraint set) is defined as the set $\{x | g_j(x) \le 0, j = 1, 2, \ldots, m$; and $h_i(x) = 0, i = 1, 2, \ldots, e\}$ (Marler & Arora, 2004).

Multi-Objective Optimization has been used to predict: joint displacement; musculoskeletal discomfort; potential energy (Gagg, Yang, & Howard, 2012; Marler, Arora, Yang, Kim, & Abdel-Malek, 2009). An advantage of this approach is that one just needs to add additional constraints for different scenarios (Yang, Marler, & Rahmatalla, 2010).

In this paper, S_b is used as the objective value. Joint angles a_i are taken as predictor variables. By using Multi-Objective Optimization, minimal S_b (where risk of neck and trunk is the lowest) can be calculated out when a_i is optimal. Based on the standing posture of surgeons, joint angle restraints will be implemented. In the following definition, the reader can refer to Figure 3(a) for the specific links (l) and specific angles (a) used in the calculation. In this model, the end of instruments must touch the operation position on the operation table. It is assumed that avatar in the digital anthropometric model should see the instruments (I) at the operating position (O) at a working distance (WD) and declination angle (DA) (see Figure 3(b)). l_h is equal to table height (TH), and l_e is the length of eye line in Figure 3. The values of a indicate the angles of the various joints in the model (see Table 1). The optimization problem is defined as follows:

$$\text{Find } a = \left[a_1 a_2 \cdots a_{12}\right] \tag{4}$$

$$\text{Minimize } F(a) = S_b = F\left[F_1(a_{ne}), F_2(a_{tr})\right] \tag{5}$$

Subject to:

$$\begin{aligned} h_1 = {} & abs(l_6 * \cos(a_7 + a_6) + l_7 * \cos a_7 + l_8 + l_9 + l_{10} + l_{11}) \\ & - abs(l_5 * \cos(a_7 + a_6 + a_5) + l_e * \cos(a_7 + a_6 + a_5 + a_4 + a_e) \\ & + l_v * \cos(a_7 + a_6 + a_5 + a_4 + a_v) + l_h) \end{aligned} \tag{6}$$

$$\begin{aligned} h_2 = {} & abs(l_1 * \cos(180 - a_1) + l_2 * \cos(180 - (a_1 + a_2)) \\ & + l_3 * \cos(180 - (a_1 + a_2)) + l_t * \cos a_t) - abs(l_5 * \cos(a_7 + a_6 + a_5) \\ & + l_v * \cos(a_7 + a_6 + a_5 + a_4 + a_v) + l_e * \cos(a_7 + a_6 + a_5 + a_4 + a_e)) \end{aligned} \tag{7}$$

$$\begin{aligned} h_3 = {} & abs(l_1 * \sin(180 - a_1) + l_2 * \sin(180 - (a_1 + a_2)) \\ & + l_3 * \sin(180 - (a_1 + a_2)) + l_t * \sin a_t) - abs(l_5 * \sin(a_7 + a_6 + a_5) \\ & + l_v * \sin(a_7 + a_6 + a_5 + a_4 + a_v) + l_e * \sin(a_7 + a_6 + a_5 + a_4 + a_e)) \end{aligned} \tag{8}$$

$$h_4 = a_3 - a_2 \tag{9}$$

$$g_1 = a_1 - a_6 \tag{10}$$

$$a_i^L \le a_i \le a_i^U \tag{11}$$

Equations (6–11) define constraints for the model as follows. Equation (6) defines the vision constraint allowing standing surgeon to see clearly the instrument based on the assigned WD and TH. h_1 must be

equal to zero when minimal S_b is gained. Equation (7) defines the vertical position of instrument. Equation (8) defines the horizontal position of instrument. h_2 and h_3 must be equal to zero when minimal S_b is gained. Equations (7) and (8) ensure the surgeon to touch the operation field with the instrument meanwhile seeing the instrument. Equation (9) defines the wrist joint keeping no bent. h_4 is zero as minimal S_b is gained. Equation (10) defines the upper arm swinging forward. g_1 is less than zero as minimal S_b is gained. Equation (11) defines the inequality constraint of joints angle based on Table 1.

Based on the surgeon's standing posture, a_i will be limited by the upper and lower values that satisfy all of the constraints in Equations (6–11). Thus, the aim is to define the working posture to be modelled, in terms of the key constraints that affect the posture when performing a given type of task using a given set of equipment, and then to calculate the potential risk score (defined by RULA Table B) that relates to a person of a given stature adopting this working posture.

3. Results

In order to demonstrate the application of the approach followed in this paper, ten avatars are considered with standing height from 5% female up to 95% male digital human models. The interrelations among S_b, *SS*, *WD* and *TH* are then analysed based on ten digital human models.

The surgeon stature (*SS*) range is from 1,534 to 1,864 mm. Table height (*TH*) is from 800 to 1,250 mm (increment is 50 mm). When *SS* and *TH* are changed according to the mentioned values as above, minimal S_b can be calculated out by using Multi-Objective Optimization. The results are shown in Table 4. Every minimal S_b is got based on the optimal *AN* and *WD*. The corresponding *AN* and *WD* are separately shown in Tables 5 and 6.

3.1. Predicting risk of discomfort (calculating S_b)

Table 4 shows the interactions between S_b, *SS* and *TH*. The top zone, with the "–" symbol indicates no solution. For the green zone, $2 \le S_b < 3$. For the yellow zone, $3 \le S_b < 4$. For the red zone, $S_b \ge 4$. From Table 4, author make the following observations:

(1) When $TH \in \{1{,}200, 1{,}250\}$, Surgeon Stature ≤ 95% female and < 50% male do not have solutions.

(2) ≤ 5% female does not have a solution when *TH* = 1,150 mm.

(3) When $TH \in \{1{,}000, 1{,}050, 1{,}100, 1{,}150\}$, $S_b \le 3$, indicating negligible risk for all values of SS except M_{95}. When *TH* is between 1,050and 1,150 mm, 93% populations lie in the green zone. So this range of table height is recommended.

(4) When $TH \in \{850, 900, 950\}$, $S_b > 3$ for all Males and is close to 3 for most Females.

(5) When $TH \in \{800, 850\}$, $S_b > 4$ for all SS greater than F_5. This table height should be avoided.

3.2. Calculating neck angle (AN)

Table 5 shows the interactions between *AN*, *SS* and *TH*. *AN* is a response to S_b in Table 4. The top zone, white and with the "–" symbol indicates no solution. The green zone, *AN* is $12 \le AN < 24$. In the yellow zone, *AN* is $24 \le AN < 35$. In the red zone, *AN* is $AN \ge 35$. Assuming that cervical symptoms are more common as neck flexion in excess of 15° (Capone et al., 2010), and maximum head tilt should be less than 20° (Valachi, 2008), author define 15° as the criteria for risky posture and 20° as critical. In Table 5, risky values of AN are shown in **bold** and critical values in ***bold italic.*** Table 5 shows how $TH \in \{800, 850, 900, 950\}$ creates problems for most of the values of SS, and even the range of 1,000 to 1,150 poses risk in terms of neck angle.

3.3. Calculating working distance (WD)

Table 6 shows the interactions between *WD*, *SS* and *TH*. *WD* is response to S_b in Table 4.The top zone, white and with the "–" symbol indicates no solution. The green zone, *WD* is $380 \le WD < 700$. In the yellow zone, *WD* is $560 \le AN < 760$. In the red zone, *WD* is $620 \le WD < 760$. Recall that the recommended working distance when wearing loupes is 34–50 cm. From this, it is assumed that values

Table 4. S_b scores as wearing 25 degree loupes

Table height (TH) (mm)	Surgeon stature(SS) (mm)									
	F_5	F_{25}	F_{50}	M_5	F_{75}	M_{25}	F_{95}	M_{50}	M_{75}	M_{95}
	1,534	1,596	1,634	1,652	1,672	1,715	1,734	1,758	1,801	1,864
1,250	–	–	–	–	–	–	–	–	2.18	2.27
1,200	–	–	–	–	–	–	–	2.35	2.35	2.44
1,150	–	2.18	2.35	2.27	2.27	2.27	2.35	2.35	2.44	2.44
1,100	2.27	2.27	2.27	2.35	2.27	2.35	2.27	2.53	2.46	2.74
1,050	2.35	2.44	2.35	2.44	2.53	2.63	2.63	2.63	2.86	3.00
1,000	2.46	2.53	2.63	2.46	2.74	2.74	2.56	2.51	3.00	3.16
950	2.63	2.86	2.56	3.00	3.00	3.00	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	4.80
800	3.53	4.15	4.15	3.94	4.11	4.15	4.29	4.29	4.29	4.96

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Table 5. *AN*(degree) as wearing 25 degree loupes (degree)

Table height (*TH*) (mm)	Surgeon stature(*SS*) (mm)									
	F_5	F_{25}	F_{50}	M_5	F_{75}	M_{25}	F_{95}	M_{50}	M_{75}	M_{95}
	1,534	1,596	1,634	1,652	1,672	1,715	1,734	1,758	1,801	1,864
1,250	–	–	–	–	–	–	–	–	12.86	14.50
1,200	–	–	–	–	–	–	–	15.19	15.20	16.54
1,150	–	13.45	15.10	14.70	14.20	13.97	15.88	16.23	17.20	17.49
1,100	15.06	14.32	14.16	15.76	15.01	15.89	15.64	17.96	18.87	*20.91*
1,050	15.35	17.78	16.14	16.88	19.12	19.80	19.52	*20.58*	*23.29*	*24.63*
1,000	18.88	18.56	*20.68*	18.38	*21.33*	*21.73*	19.92	*20.68*	*25.30*	*27.15*
950	*20.14*	*22.49*	*20.68*	*24.10*	*24.95*	*25.57*	*26.42*	*27.06*	*31.13*	*31.64*
900	*23.58*	*26.07*	*27.73*	*28.48*	*28.46*	*29.58*	*30.40*	*31.25*	*32.81*	*37.87*
850	*27.82*	*29.63*	*30.57*	*30.58*	*33.91*	*33.67*	*34.50*	*37.06*	*37.43*	*45.19*
800	*30.84*	*35.99*	*36.31*	*34.92*	*37.93*	*37.74*	*39.10*	*38.91*	*39.74*	*49.42*

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Table 6. *WD*(mm) as wearing 25 degree loupes (mm)

Table height (TH) (mm)	Surgeon stature(SS) (mm)									
	F_5	F_{25}	F_{50}	M_5	F_{75}	M_{25}	F_{95}	M_{50}	M_{75}	M_{95}
	1,534	1,596	1,634	1,652	1,672	1,715	1,734	1,758	1,801	1,864
1,250	–	–	–	–	–	–	–	–	540	580
1,200	–	–	–	–	–	–	–	520	560	620
1,150	–	400	440	460	500	540	540	560	600	680
1,100	380	460	500	500	540	580	600	620	640	700
1,050	440	480	540	560	560	600	620	640	660	720
1,000	440	540	560	580	600	640	660	660	700	740
950	520	560	600	600	620	660	680	680	700	760
900	540	580	620	620	640	680	700	700	740	760
850	560	620	640	660	660	700	720	720	760	760
800	600	620	660	680	680	720	720	740	760	760

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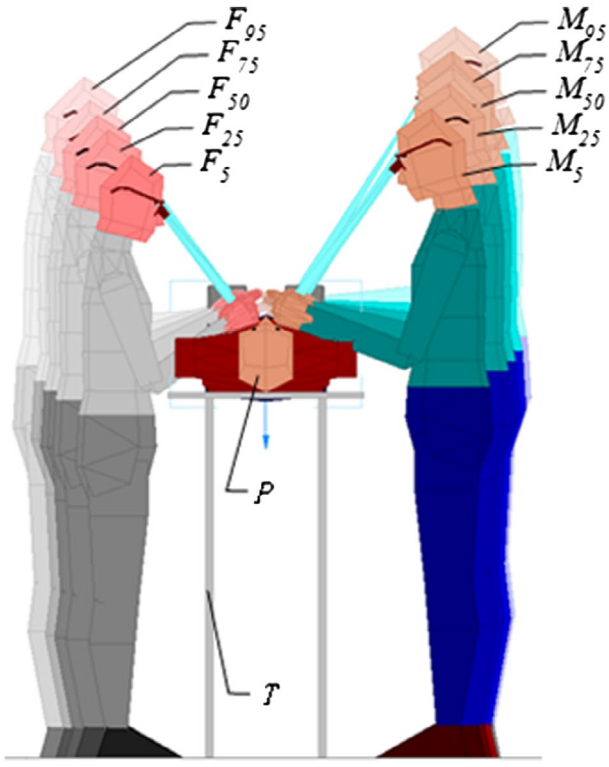

Figure 4. Virtual scene of surgeon doing operation as *TH* = 1,100 mm.

Notes: 10 digital anthropometric models are shown. P is the patient. T is the operation table.

above 500 mm could be problematic because there will be a compromise between the viewing distance at which loupes focus clearly and the working distance of the surgeon. In Table 6, these values are shown in **bold** and imply that majority of the surgeons will need to adjust their posture in order to work at these table heights.

4. Discussion

Tables 4–6 show how it is possible to decrease the angle of neck by adjusting the table height, or by changing the working distance. For the same *SS*, *WD* has an inverse correlation with *TH*. If *TH* becomes too low, *WD* will increase leading to an increase in *AN*. For example, consider M_{50} working at different table heights. For all values of *TH*, the working distanced (*WD*) exceeds the proposed value of 500 mm and, from 1,200, the neck angle is greater than 15° and the RULA risk increases beyond 3 with *TH* < 1,000 mm.

From the analysis of ten digital human models, *TH* = 1,100 mm appears suitable for most surgeons. Using this assumption, and the results shown in Tables 4–6, a virtual scene is built in SAMMIE, as shown Figure 4. Figure 4 shows surgeons of different stature can have an optimal posture when they work together. In order to achieve comfortable neck angle, they must wear loupes with matching viewing distance, stand at the correct distance from the table and maintain appropriate joint angles of arm to ensure that the instrument can touch the object. While this is the ideal (based on our analysis), this also highlights the potential for risk to vary as the operation progresses. For example, it is often necessary to change posture, either to affect a task, or to improve vision, or to collect or pass over an instrument. Consequently, while the ideal model illustrates the desirable, static postures, these are likely to change with the operation. The point that author would make here is that there are regions (as shown in Tables 4–6) in which the predicted risk of neck injury (defined by RULA scores) will increase for surgeons of specific stature working at *WD* defined by the viewing distance of their loupes.

Given the number of reports of musculoskeletal injury (particularly to the neck), it is possible that current practice does not consider the range of the postures that will be encountered. It is proposed that, rather than complicating the fitting procedure, it could be beneficial to use the process outlined in this paper (or a modified and simplified version) to conduct additional checks on the use of the loupes and to provide advice and guidance on appropriate settings for *TH* and *WD*, given loupes of a particular prescription and specification and surgeon of a particular stature.

5. Conclusions

The study shows how RULA scores change for different table heights and working distance during an operation. Of particular interest to our work is that fact that head-mounted magnifiers (loupes) constrain the working distance by their viewing distance. It is shown how *WD* interacts with the stature of surgeon. RULA is a useful assessment value for posture prediction. The result shows that reasonable table height and working distance of loupes for surgeon could decrease the flexion angle of neck. Certainly when loupes are fitted to a surgeon (and all loupes are custom-modified and fitted as bespoke equipment for surgeons), there is the need to consider how the viewing distance and angle corresponds to the likely activity of the surgeon. Anecdotal evidence suggests that fitting typically takes place when the surgeon is seated, without performing surgical (or simulated, at least, surgical) tasks and in an environment which differs from the operating theatre. Consequently, the fitting will rely on the experience of the surgeon (in judging likely values of *WD*) and the expertise of the loupe-fitter (in terms of calculating viewing angle).

Practitioner summary

This paper demonstrates how risk of musculoskeletal discomfort (defined using RULA scores) can be predicted using virtual human models. The approach is applied to the surgeons who wear head-mounted magnifiers and report a neck injury.

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