Posture prediction of a human on a chair: model validation

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Abstract One of the aspects that influence the sitting comfort is the distribution of the pressure applied to the skin by the seat surface. In the scientific literature, many studies show experimental activities in order to evaluate the influence of pressure distribution at the seat-human interface on the comfort evaluation. The main limitation in seat design is based on the difficulties to predict the contact pressures distribution without prototypes because of the complex interaction among body muscles, wearing, human's anthropometric characteristics, shape and materials of the seat. Moreover, the same human can assume different postures on the same seat, and different people, seated on the same chair, can assume different postures even if they have the same anthropometric percentile. The aim of this study is to propose a mathematical model evaluating interaction loads between human segments and seat segments. In this model a human body represented by 8 segments is placed on a 6 segments seat with posture dependent on seat segments and on position of the cocciyx on seat and feet on floor. Human segments can be configured in length and weight and friction between body and seat is considered. A model validation study based on an experimental comparison with contact pressures is also presented.

Keywords: Seating posture, seat, contact pressures.

1 Introduction

The study of the interaction between chair and posture to predict the comfort level of a seated person is necessary for the correct design of any type of chair. The scientific literature recognizes, from the experimental point of view, the analysis of contact pressures and the analysis of comfortable postures the most significant aspect to be investigated [1-16].
In the paper "Posture prediction of a human on a chair: model prediction" authors presented a mathematical model that has been developed and tested in order to determine how the weight of a human body is distributed on a chair. This model allow the study of the unconscious logics that determine the choice and maintenance of a posture assumed during sitting. It is an open problem because for the same human on the same seat, we observe very different postures An experimentation phase is now possible about this model comparing pressure pad results with model results in order to find any recursion of stress values of the articular joints or in assumed postures, highlighting seating comfort drivers.
Knowing the comfort needs of a seated person means knowing which inclinations the various parts of his body need to assume and in which area he needs to have more support to reach a comfortable seating. This allows designing of any type of seat to accommodate a human in order to optimize it from the point of view of comfort.

2 Model description

The model is based on a static analysis, in which body and seat are seen in profile and are considered as set of segments on a two-dimensional plane; human articulation are represented by joints that allow rotations but not translations. To simulate in the best way the different assumable posture, human body has been schematized with 8 segments (Figure 1): head and neck, upper trunk, lower trunk, buttock, thigh, leg, sole of the foot, toes.

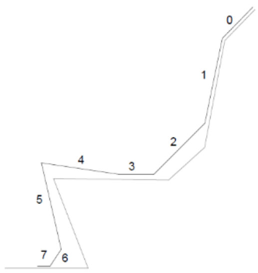

Fig. 1. Schematisation of human body with 8 segments: 0 – head and neck; 1 – upper trunk in contact with the backrest; 2 -trunk part with no contact; 3 – leg part always in contact (buttock); 4 – upper leg (thigh); 5 – lower part.

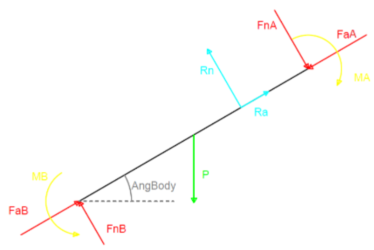

Fig. 2. Loads on a segment

The arm's weight is summed to the one of the upper trunk, that of thighs, legs and feet is counted twice. The trunk's length is divided into the upper and the lower trunk part in proportions 1/3 and 2/3 to make difference between lumbar and thoracic part. There are different kind of seat, depending on the context in which they are used and we used six segments to model it: headrest, backrest, upper part, backrest, lumbar part, sitting plan, legs support, footrest. To each segment for which is expected contact with the body, it's assigned a friction coefficient.

The model calculates the posture starting from the seat coverage percentage $\boldsymbol{K} = PosBacino * LengSed_{(i)}$ (Figure 3) calculated from the side of the knees. Starting from the buttocks position, we calculate (Figure 4) the position of the thoracic part and the extension of the corresponding contact surface compared to the eventual back of the chair. Then we calculate the eventual contact in the lumbar area and the head position compared to the headrest.

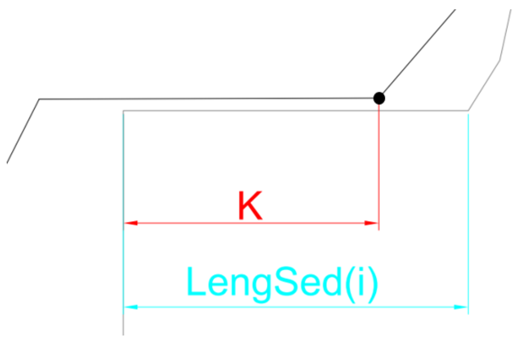

Fig. 3. Back on seat.

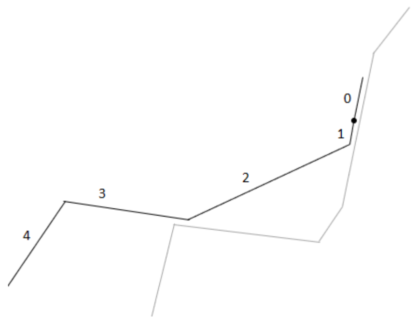

Fig. 4. Human seated at the extreme of the chair.

The second postural parameter imposed is the leg angulation $AngKnee$, both forward and backward compared to the thigh. In this way it is also controlled the feet contact on the floor or on the footrest and the possible contact of the thighs on the seat.
Depending on the upper trunk position or headrest configuration, the head angle and contact head on is calculated. As an example in Figure 5 a) Trunk longer than the back and headrest backwards with an angle greater than 45 °; b) Trunk longer than the back and headrest backward with an angle smaller than 45 °; c) Trunk shorter than the backrest, headrest forward, the contact occurs only with the top of the head.

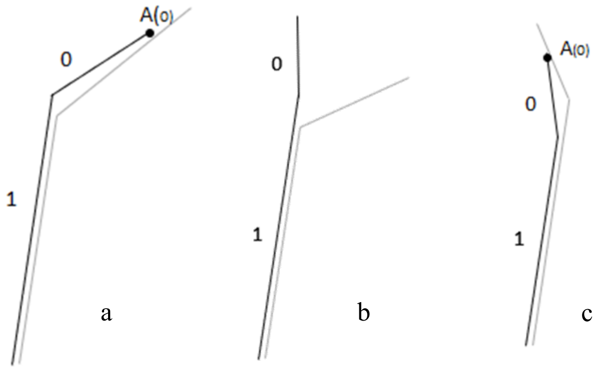

Fig. 5. Samples of head posture

Once the posture and the contact forces position are determinated we can analyse loads and equilibrium conditions considering weights and frictional forces between the foot and the footrest and between the body segments and the seat segments.
For each segment, all the equilibrium conditions are calculated compared to the local reference system, imposing that in the joints between segment and segment it must result the equality of the resulting forces and torques on the two sections. The segments head and toes have both a free extreme where forces and torques assume null value. The frictional force is $R_{a(i)} = R_{n(i)} * Mu_{(i)}$.
For the purposes comfort, it was considered preponderant to keep the muscular efforts necessary to guarantee the moments present in the joint joints low. From the count of equations and unknowns, it result to be indeterminate 6 values for which it is necessary to make some hypotheses.
In particular at the moment is possible to choose among 4 options in function of the type of study that we desire to make and of the related scientific literature:

1) impose null torques condition as ideal condition
2) impose as ideal condition the one in which all torques are equal
3) impose known values in place of unknown torques
4) make a study of torque's variability in a wide range
5) impose a constant ratio between thigh contact pressure and pelvis contact pressure

4 Experimental setup and model validation

To evaluate the proposed model, it was made a comparison of the numerical results obtainable by varying the unknown torques in a wide range with those deriving from the pressure measurements obtained during an experimental phase carried out in the laboratory.

The experimental phase implicated the use of the chair shown in Figure 7 on which a measuring mat of the contact pressure was placed.

Fig. 6. Chair used in experimental tests

There isn't headrest, so the head-neck segment is always upright (section 0, $LengSed_0 = 0cm$); the backrest allows the contact only for the part indicated in yellow in the previous imagine (section 1, $LengSed_1 = 26cm$); the blue part is, instead, the one where there is no contact because it's empty (section 2, $LengSed_2 = 12cm$); the sitting plan, indicated in black, corresponds to the section 3 of length $LengSed_3 = 46cm$; the sitting plan is $41cm$ $(= LengSed_4)$ far from the ground, and this distance represents the section 4 on which, however, there is no contact; there's no footrest so the section 5, on which the foot lean, correspond to the floor. His length is set as equal to that of the foot $(LengSed_5 = LengBodySeg_5)$.
The inclinations of the seat chosen, compared to the floor, are: Segment 0: absent; segment 1: 88 °; segment 2: absent; segment 3: 0 °; segment 4: it is represented by a distance but physically does not provide support; segment 5: 0 °.
The friction coefficients have been set, hypothetically, all equal to 0.3 with the exception of that of the foot, chosen equal to 0.4. The standard time to which the tests refer is equal to 1 second and the acquisitions took place every 0.04 seconds, for a total of 25 pressure states. This result has been compared with the normal reaction explicated by the sitting plan on the said segment, equal to $R_{n(3)}$, calculated by the program.
The tests were carried out on 4 different subjects; the pressures exercised on the sitting plan by each of them were measured for three different knee inclinations: 1) 90 °; 2) legs forward in the most comfortable position; 3) back legs still in the most comfortable inclination. Each subject was photographed and the position of the pelvis compared to the chair and the values of the knee angles were taken from the photo.

5 Results and considerations

In Table 1 there are the ranges of results (minimum and maximum values) of the acquisitions made with the pressure mat, in the 25 fractions of a second, compared to the $R_{n(3)}$ calculated with the six-segments model for the four subjects and for the three knee angles (AngKnee) for right leg, stretched leg and leg under seat :

Table 1: Characteristics of the subjects that have participated to the experimentation.

ID	Weight (kg)	Height (cm)	Ang Knee (deg)	RN measured min (kg)	RN measured max (kg)	RN measured media (kg)
1	71	170	90	31.2	38.5	35.5
			147	50.1	55.3	53
			51	49	53.4	51.5
2	71	162	90	20.8	25.7	23.7
			148	35.2	39	37.1
			45	28.2	33.8	31.2
3	53	165	90	24.5	29.5	26.3
			146	29.2	37.1	32.6
			50	30.2	37.6	34
4	63	170	90	33.4	37.3	34.9
			162	31.6	38.8	35
			44	34.4	38.2	36.9

The mathematical model was applied varying the torques applied to the knees, hips and sacral joint from 0 to 100 kg * cm with step 5, thus analysing 9261 possible combinations. Table 2 shows results for one of simulated subjects.

Table 2: Load conditions of the joints corresponding to the experimental data for the Subject 1.

AngKnee	M_{hip}	M_{leg}	M_{knee}	P_{pelvis}	P_{leg}	P_{foot}	P_{carpet}	Real P_{carpet}	Toll.
51	**35**	**30**	**0**	23.6	24.5	42.5	48.1	51	±3
	40	25	5	23.6	24.5	42.5	48.1		
	…	…	…	…	…	…	…		
	65	0	30	23.6	24.5	42.5	48.1		
90	25	45	0	18.6	18.2	65.1	36.8	35	±3
	30	**40**	**5**	18.6	18.2	65.1	36.8		
	35	**35**	**10**	18.6	18.2	65.1	36.8		
	40	**30**	**15**	18.6	18.2	65.1	36.8		
	45	25	20	18.6	18.2	65.1	36.8		
	…	…	…	…	…	…	…		
	70	0	45	18.6	18.2	65.1	36.8		
147	**40**	**20**	**0**	28.6	25.8	29.9	54.4	52.5	±3
	45	15	5	28.6	25.8	29.9	54.4		
	…	…	…	…	…	…	…		
	60	0	20	28.6	25.8	29.9	54.4		

The resultant of the experimental measurements obtained from the mat is compared with the sum of the normal force acting on the buttocks ($R_{n(3)}$) and of that acting on the thigh ($R_{n(4)}$). In particular, all the combinations of joint moments that result in the load value on the seat corresponding to the measured value with a certain tolerance (± 3 kg corresponding to the load oscillations during the acquisition interval) have been identified. Among these, the combinations for which the component relative to the thighs and that relating to the buttocks are equal (unless of the same tolerance value) have been identified since this condition corresponds to a better pressure distribution which induces greater comfort or less discomfort. Table 1 shows the results about one subject.
The moment applied to the hip (more precisely to the sacral joint) conditions the other two, therefore depending on the activation of the back there will be a consequent activation of the leg muscles. M_{hip} varies on average between 20 and 65; M_{leg} and M_{knee}, instead, between 0 and 40. The extent of these intervals, based on the information collected, proportionally depends on the overall weight of the subject.
Since the sacral and lumbar joints have the same axis of rotation and must both hold the weight of the upper part of the body, we assume that in conditions of comfort they exercise the same level of effort. In this hypothesis the results are further filtered by choosing the solutions for which | Mhip-Mleg | <= 10 (sum of tolerances on both moments).
From the analysis of the data it results that, in the hypotheses carried out and comparing the simulations with the experimental results, we tend to always assume the same values of articular stress, which grow linearly in proportion to the weight, as shown in the Table 3, independently from the position of the legs stretched forward, straight or placed under the pelvis.

Table 3: Load conditions of the joints corresponding to the experimental data for the Subject 1.

Weight	Leg ahed			Vertical leg			Leg behind		
(kg)	Mhip	Mleg	Mknee	Mhip	Mleg	Mknee	Mhip	Mleg	Mknee
53	27.5	22.5	2.5	27.5	22.5	2.5	27.5	22.5	2.5
68	30.0	30.0	5.0	30.0	30.0	5.0	30.0	30.0	5.0
71	38.8	33.8	15.0	35.0	37.5	12.5	36.3	31.3	3.8

Conclusions

A mathematical model has been developed and tested that determines how the weight of the body is distributed on a chair, so as to study the unconscious logics that determine the choice and maintenance of a posture. The experimentation allowed to highlight that there is a remarkable recursion of some stress values of the articular joints of the pelvis, hip and knee. By imposing these values in the calculation model, it is possible to determine, for each chair configuration, which postures will be assumed by a person, and to make a preliminary assessment of the level of comfort obtainable.

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