Posture prediction of a human on a chair: model description

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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.

2 Physiological and Postural Comfort

The word "*comfort*" refers to a state of well-being perceived by an individual during any activity, and involves factors such as temperature, brightness, noise, ventilation, assumed posture, level of anxiety, level of fatigue, or anything that alters human physiology. The Vink-Hallbeck model [1] of comfort perception shows how the factors that act on comfort can be grouped into few large categories that refer to external aspects during the use of the product, to the product, and to the subjectivity of the user.

The perception of the comfort of a chair depends, in a objective manner, on the human assumed posture that depends, in a still objective manner, on how the chair is designed, but also on the subjective way in which the person decides to sit.

Another fundamental factor is the duration of the interaction: it is easy to observe how, regardless of the comfort level of a chair, each of us after a certain period of time changes posture (without changing the chair). For example, there are numerous correlation studies between the micro-movements of the person and the level of perceived discomfort. Macromovements are instead a consequence of the type of human activity on the chair, but also a sign of the need to relax muscles that have guaranteed the posture up to that moment or to lighten the level of pressure localized in the areas of contact that causes a reduction in blood circulation.
The comfort of the seat is a topic of considerable importance in the field of transport, but not only, considering that each of us carries out many activities (working, eating, studying, ...) sitting on a chair or relaxing sitting on armchairs. The design of a seat, whatever it is, must adequately predict the level of comfort perceived by the user.
Currently it is difficult to predict the comfort of a seat except from the experimental point of view, using prototype versions of the product trying to overcome the effects of experimental reliefs on the perception of comfort [2]. There are two main lines of thought: the first believes that the factor to consider, in the search for constructive geometry, is the contact pressure while the second directly measures the assumed posture of the various parts of the body.
In the first case we focus mainly on the back of the thigh and on the buttocks, areas in which most of the load is discharged [3-7]. We try to limit the average pressure as much as possible by increasing the contact surface. For example, the study by Noro et al. [8] starts from the idea that from the posture assumed by those who practice Zen meditation, which is maintained long time, indications can be obtained for the design of a session for a specific application. A seat is created (Figure 1) that reproduces the same contact pressures obtained on meditation cushions that optimize posture by providing support to the lumbar area, taking into account the differences linked to surgical activity.

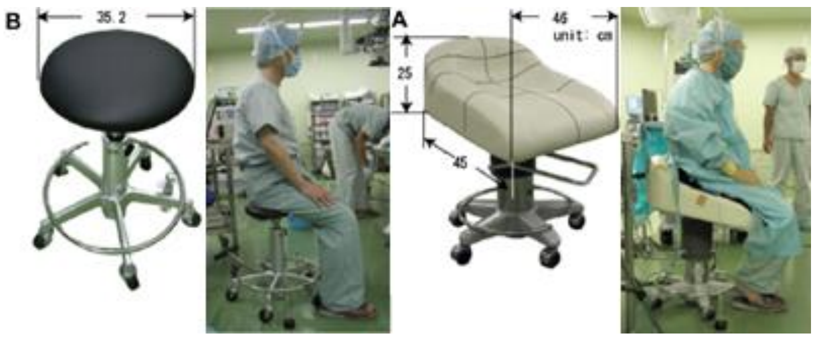

Fig. 1. Standard surgical chair and zen surgical chair.

In the case of posture analysis, the focus is mainly on the position of the back, legs and head [9-18]. Figure 2 shows how excessive inclinations generate shear stresses on muscles and skin that limit, once again, the passage of blood. The inclination of the back slightly affects the extent of the shear stress, while it greatly influences the geometry assumed by the spine, with minor consequences such as headache, shortness of breath, pain in the neck, wrists, back and vision problems , as well as real diseases: dorsal hypercyphosis, epicondylitis, carpal tunnel, loss of elasticity of the optic nerve, myopia. The most deleterious cases are those with an inclined seat. Some studies published in the journal Experimental physiology in 2015, have shown that 3 hours of seated position (body sitting) without interruptions lead to a reduction in the physiological vasculature in the body by 33% (reduction in the number of vessels that allow the passage of blood) and that this prolonged position is associated with an increase in cardiovascular diseases.

It can therefore be said that assuming a correct posture is essential to avoid the aforementioned back problems and high cutting efforts, but for the purpose of comfort it is also necessary to distribute the loads in the best possible way and find configurations in which the muscles are activated the least possible.

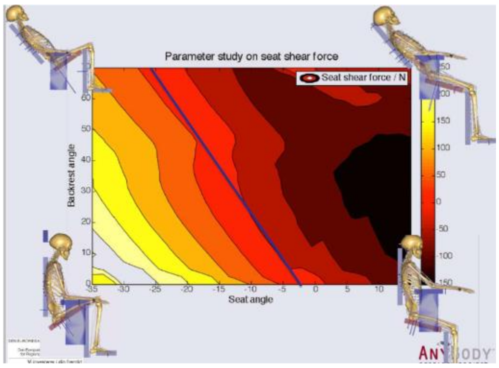

Fig. 2. Shear stress vs. seat angles.

This work presents a predictive mathematical model of postures that can be assumed by a human being seated as a function of the anthropometric measurements and the geometry of the chair, including the calculation of the consequent articular and shear stresses on the skin.

3 A simulation model of the sitting

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. For the realization of these simulations was used the program Python.
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.

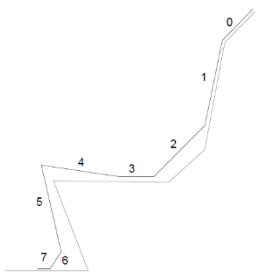

Fig. 3. Schematisation of human body with 8 segments: 0 – head and neck; 1 – upper trunk in contact with the backrest; 2 -trunk part with no contact; 3 – leg part always in contact (buttock); 4 – upper leg (thigh); 5 – lower part.

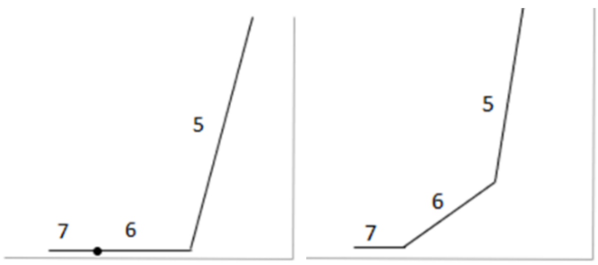

Fig. 4. a) Foot totally in contact; b) Foot in contact but with the sole lifted

This allow to consider also that cases in which, for the the moderate height of the seat, instead of stretching out foot forward the thigh are lifted from the sitting plan: the buttock part, in this case, however remains in contact

and it corresponds to one of the additional parts of this model. It is also possible to vary the foot position that changes depending on whether person is sitting with legs forward, upright or under the seat (Figure 4), so the forepart of the foot is always in contact with the respective support (footrest or floor). His length and his weight are fractions of the total values that pertain to the foot (taken from the percentile Table 1). It has been seen that, generally, toes have length and weight equal to 1/3 of those of the whole foot.
Each segment, for which it's indicated the length, the angle compared to the horizontal and the weight, will be subject to the loads coming from the hinges, to his own weight and to the contact forces with the seat. The inclination of the generic anatomical segment compared to the floor is equal to $\boldsymbol{AngBody_{(i)}}$ and his length has been indicated as $\boldsymbol{LengBodySeg_{(i)}}$.

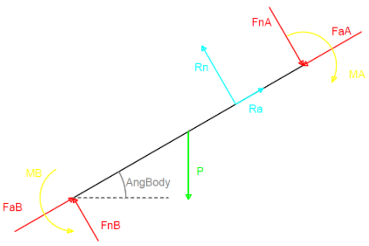

Fig. 5. Loads on a segment

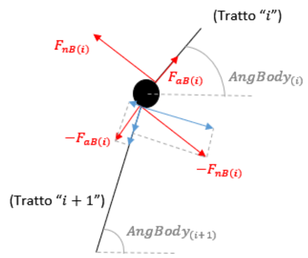

Fig. 6. Loads conversion from segment i to segmenti i+1

The weight $\boldsymbol{P_{(i)}}$ of the various parts of the body acts in the middle of the segments ($LengBodySeg_{(i)}/2$) at a distance from the respective bond $B_{(i)}$ equal to $\boldsymbol{LengCoGSeg_{(i)}}$. It is counterbalanced by external torques $\boldsymbol{M_{A(i)}}$ and $\boldsymbol{M_{B(i)}}$, applied to the constraints from the muscles and by bond's reactions $\boldsymbol{F_{A(i)}}$ ed $\boldsymbol{F_{B(i)}}$, of which we consider the components in axial and normal directions of the segment: $\boldsymbol{F_{aA(i)}}$, $\boldsymbol{F_{aB(i)}}$, $\boldsymbol{F_{nA(i)}}$, $\boldsymbol{F_{nB(i)}}$.

Table 1. Percentile weights and lengths of the various parts of the body [19, 20]

Segment	*Segment mass / Total body mass*	*Segment length / Total body height*
Hand	0.0060	0.108
Forearm	0.0160	0.146
upper arm	0.0280	0.186
forearm and hand	0.0220	0.108
total arm	0.0500	0.259
Foot	0.0145	0.152
lower leg (calf)	0.0465	0.285
upper leg (thigh)	0.1000	0.245
total leg	0.1610	0.530
head and neck	0.0810	0.182
Trunk	0.4970	0.288

The reference system used for the single part is that linked with the one (local system, relative system), with origin in $B_{(i)}$, axis of the abscissas coincident with the segment and axis of the ordinates normal to it. The weight

and the height of the considered person are divided on the various segments based on percentiles of Table 1 to obtain weights $P_{(i)}$ and lengths $LengBodySeg_{(i)}$:
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. They differ in various aspects but those of interest to us are geometry and shape. An automotive seat follow the body's shape from the trunk downwards leaving the legs free; the chaise longue of a psychologist also supports these one, while a generic kitchen chair usually doesn't provide head support.
So we can find a scheme that allows us to characterize every kind of seat; they can be used up to six segments: headrest, backrest, upper part, backrest, lumbar part, sitting plan, legs support, footrest. The inclination compared to the floor and the length of the generic segment of the seat are respectively equal to $\boldsymbol{AngSed}_{(i)}$ and $\boldsymbol{LengSed}_{(i)}$. To each segment for which is expected contact with the body, it's assigned a friction coefficient $\boldsymbol{Mu}_{(i)}$.

Contact between Body and chair

Depending on the size of the body segments and on the seat configuration, for those anatomical segments that eventually rest on the chair, the intersection part between seat segment and body segmenti is considered as the contact surface.
For the segments in contact, the force $\boldsymbol{R}_{(i)}$ is applied in the center of gravity of the contact pressures indicated with the distance $\boldsymbol{l}_{\boldsymbol{R}(i)}$ from the constrain $B_{(i)}$ and decomposable in normal support reaction $\boldsymbol{R}_{\boldsymbol{n}(i)}$ and in the friction force $\boldsymbol{R}_{\boldsymbol{a}(i)}$.
The determination of the seated body posture starts from the hypothesis that the first segment that interacts with the chair is represented by the buttocks and that the rest of the body adapts later. If the posture obtained is not satisfactory, the position is remodulated compared to the seat until the most comfortable posture is reached.
The model calculates the posture starting from the seat coverage percentage $\boldsymbol{K} = PosBacino * LengSed_{(i)}$ (Figure 7) calculated from the side of the knees. Starting from the buttocks position, we calculate (Figure 8) 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.

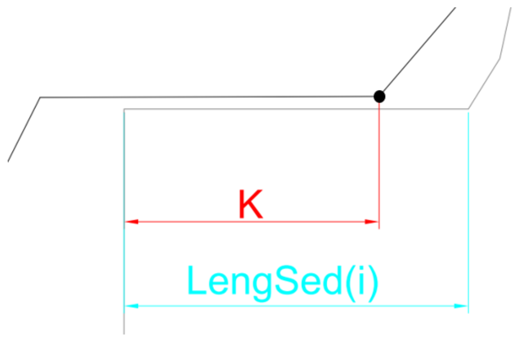

Fig. 7. Back on seat.

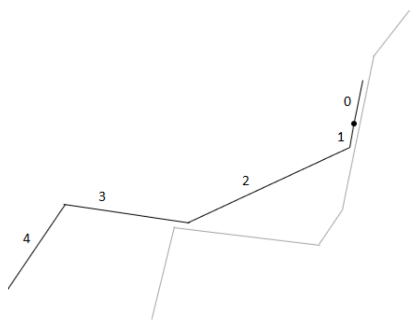

Fig. 8. Human seated at the extreme of the chair.

The second postural parameter imposed is the leg angulation $\boldsymbol{AngKnee}$, 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 9 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.

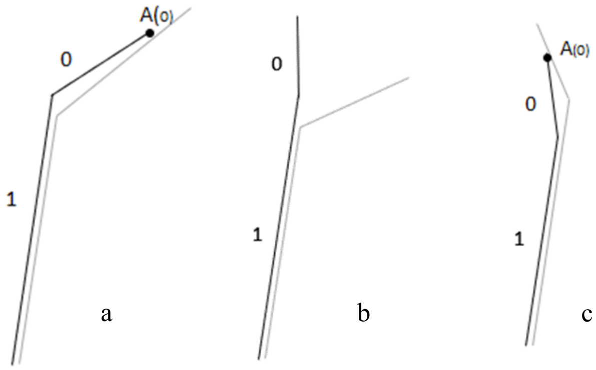

Fig. 9. Samples of head posture

Once the posture is defined and the extensions of the contact surfaces between the body segments and the seat segments are calculated, it is calculated the position $l_{R(i)}$ in which is applied the contact force $R_{(i)}$. In particular, it acts in the middle point of the contact length, defined as part of the seat section on which an anatomical segment or part of it rests.

1) If the contact length is exactly equal to $LengSed_{(i)}$ the part of the seat is occupied for the 100%. This means that the anatomical segment's length it's equal or greater than the one of the respective section of the seat ($LengBodySeg_{(i)} \geq LengSed_{(i)}$), and the contact starts from the constraint $B_{(i)}$ to which reference is made. Then $l_{R(i)} = LengSed_{(i)}/2$
2) If the contact length in less than that of the seat section we can have:
    - Anatomical segment's length smaller than that of the respective seat section ($LengBodySeg_{(i)} < LengSed_{(i)}$) and the contact starts from the hinge $B_{(i)}$. As the latter is the reference point for lengths, the distance from it is null and we have $l_{R(i)} = LengBodySed_{(i)}/2$:
    - Anatomical segment's length smaller than that of the respective seat section ($LengBodySeg_{(i)} < LengSed_{(i)}$) and the contact doesn't start from the hinge $B_{(i)}$; in this case, to the latter relationship, it must be summed the distance between the hinge $B_{(i)}$ and the starting point of contact;
    - Anatomical segment's length equal or greater than that of the respective seat section ($LengBodySeg_{(i)} \geq LengSed_{(i)}$) but the contact takes place at a not null distance from $B_{(i)}$; to the seat section's length it must be subtracted this distance; $R_{(i)}$ is applied at half of that value.

Mathematical analysis

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 (Figure 10 and 11).
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 $R_{a(i)} = R_{n(i)} * Mu_{(i)}$.

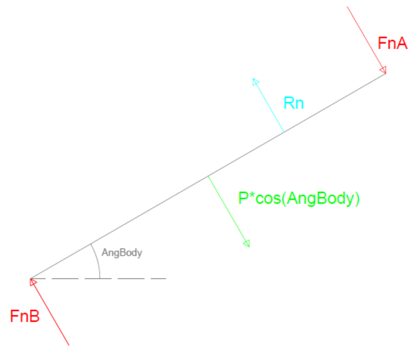

Fig. 10. Normal forces scheme acting on single element

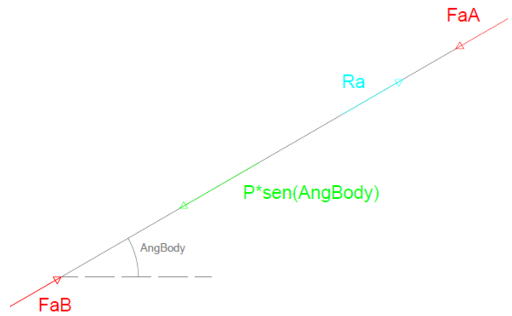

Fig. 11. Axial forces scheme acting on single element

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, it is possible to choose among 5 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

Conclusions

A mathematical model has been developed and tested that determines how the weight of the body is distributed on a chair. This model allow us to study the unconscious logics that determine the choice and maintenance of a posture. An experimentation phase is now possible 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.

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