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# Man is the measure of all things

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**Abstract**
Our system of measures referred to human proportions and human perception, as Protagoras stated, is "Man is the measure of all things". In this paper, we present an overview of the measure of Man as a travel on time from the point of view of the past historical development to the future with the insight of different disciplines such as Anthropology, Ergonomics, and Human Factors. The key concept is that all the most famous scholars, architects artists and philosophers that have been working on system of human measures such as Polyclitus, Vitruvius and Leonardo until Le Corbusier are designers of Human canonical proportion and they design the things with the measure of their "Canonical Human". We are looking to create a design with the differentiation of the measure of the "Real Humans". The real human is not a canon but can be measured applying methodological international standards to obtain an anthropological database and to represent human variability on the base of standardized statistics for ergonomic design. This essay presents the result of 50 years of study at the Laboratory of Anthropometry and Ergonomics in the Turin University (Italy), applying Anthropometry of the real human evolution and Earth adaptation as result of the main factors: "gravity", also investigated on context without this factor that is in "Outer Space". In the Laboratory, researches were conduced not only to study past and present human populations, but also to deduce potential future expectations.

**Keywords** Anthropometry · Human centred design · Gravity · Microgravity · Human factors · Outer space

## 1 Foreword

"Πάντων χρημάτων μέτρον ἐστὶν ἄνθρωπος. Τῶν μὲν ὄντων ὡς ἔστιν, τῶν δὲ οὐκ ὄντων ὡς οὐκ ἔστιν[1]

*L'homme sait enfin qu'il est seul dans l'immensité indifférente de l'univers d'où il a émergé par hasard. Non plus que son destin, son devoir n'est écrit nulle part.*[2]

"A planet created for humans" is the mental image we have of Man on Earth, our body, our abilities, the senses and the functions of every part of us are the fruit of hundreds of thousands of years (only to restrict ourselves to our origins of species) of selection and adaptation with respect to our specific gravitational environment. Without our approximately 9.8 *g* of earthly gravity we would be differently adroit. We also see important differences between humans, all co-specifics and all suitable for living on this planet of ours, but already with different characteristics and functions depending on the milieu, with extraordinary potential even with respect to extreme environments out of this planet.

However, which might be the image of humans that in a far future may inhabit the Moon? Or else, why not populate the Moon? The Moon is probably a piece of Earth or shares its same nature; it stays in the same place in the Solar System as both globes have a common centre of gravity within the Earth's surface. Nevertheless, it is fully unwelcoming and hostile. The easiest answer should be that we are not adapted to live there! Having folks travelling outside Earth's

One of the authors, Melchiorre Masali is the winner of the prize attributed by the Accademia Nazionale dei Lincei, Rome in 2018 (International Award Fabio Frassetto for Physical Anthropology).

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[1] Sophist pre-Socratic philosopher Protagoras (Πρωταγόρας; Abdera, 486.—Ionian sea, 411 BC known for the famous sophism: "Man is the measure of all things, of those that are as they are and of those which are not as they are not."

[2] Jacques Monod—Ses citations—Dicocitations™—citation (Jacques Monod 1970 p. 143).

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atmosphere is a relatively new frontier for mankind; however, the relationship between humans and the other planets has a much longer history. While a student, Johannes Kepler devoted one of his dissertations to the question: 'How would phenomena occurring in heaven appear to an observer on the Moon?' The thesis submitted by Kepler at the Tübingen University in 1593 contained some of the major questions of the human exploitation of Space. These are the questions which we try to answer from the viewpoint of Anthropology. These questions are the base for a human/environment (1 *g* or 0 *g*) interface ergonomic design, according to the Ergonomics' human scale approach (Masali et al. 2013).

## 2 Human size, shape and form

Is the human a product of the interaction between the Earth's biological and environmental system?

The shape of the body, according to Sir D'Arcy Wentworth Thompson (Wentworth Thompson 1917), depends on the interaction of the body itself with the surrounding physical world: as nature works by respecting proportions, all things have their correct measure. If we change the environment, we will have different shape, but if we change planet what might happen? What could be the effects of gravity, the most constant environmental factor, on the evolution of the human body?

In actual fact the "human form" is the consequence of a path that passes from trees dwelling option of the Primates ancestors (starting from the most ancient Prosimians Primates such as Lemurs) with a vertical posture accompanied by leaps (the so called *vertical clinging and leaping* way of walking proposed by Napier and Walker 1967) that has resulted in what we may call the a "*gravitational revolution*" because it is as if the body and in particular the vertebral column, were taken to another planet where gravity field had…turned the posture off 90° and the leaps were "ballistic" because their path was that *of projectile trajectory undistorted by engine or guidance system*. Such an interpretation was proposed in the '60ies by a little known French Anatomist, Antoine Delattre of the Libre Université de Lille, with his senior prosector anatomist Raphaël Fenart (Delattre and Fenart 1960).

In the context of the evolution of human body posture Antoine Delattre proposed the hypothesis of the preeminent function of the inner ear vestibule organ in acquiring the upright posture, considering as a key factor the interaction with the gravitational field. Such hypothesis was foreshadowed in the 30ies by the well-known Rome anthropologist Sergio Sergi in his studies on the temporal bone (Sergi 1936), and reconsidered, in different aspects, but taking into account the gravity factor by André Leroi-Gourhan in his "Mécanique vivante" (Leroi-Gourhan 1983).

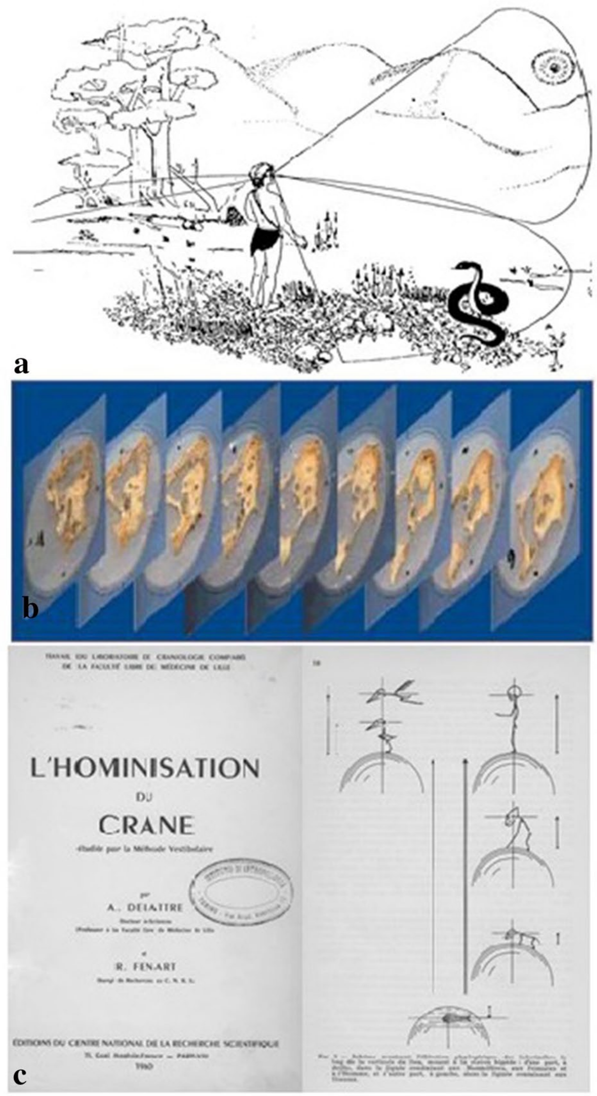


**Fig. 1** Interpretation of the vestibular versus traditional Ohr-Augen plane by E. Masali; slides of the semicircular canals; A. Delattre's hypothesis

In the Delattre's hypothesis the horizontal semicircular canal of the balance organ defines the *vestibular plane* proposed by Fernando Perez (Perez 1922) which is the reference for understanding these observable facts: in practice our arboreal path, lasted million of years, would have allowed us to "fall down" from the trees (6–12 My ago) keeping horizontal our *line of sight* (or better down 23°–28°, according to Delattre, and to our experience, to look where we put our feet: Nature is pragmatic!) (Fig. 1).

The major consequences of such course of actions may have led to the increase of the skull surface (e.g., the development of the *squama occipitalis* over the *inion protuberance)* giving a better chance to the brain to increase since the skull is now free to expand as it is supported, not limited by the spine. Moreover, a synergistic consequence is the bend of the vocal canal allowing the configuration of the articulated language. So we can really say *that Earth gravity has made Man*! This concept poses the question whether humans might also have a Darwinian "Pre-adaptation" (Matthews 1958) to the Outer Space (better with an updated expression: "Exaptation", according to Stephen Jay Gould and Elisabeth Vrba (Gould and Vrba 1982). Bearing in mind the significance of some uncommon aspects of the evolutionary paths such as the *teleonomie* (the interaction between the heritage and the constraints of the environment. Monod 1970), we may realize what could help our species to live and, why not, adapt to those environments.

Such reflections lead to outlook the characteristics of our species as a product of the interaction between all the components of the biological and environmental system in the specificity of the Earth's condition, but it becomes natural to ask ourselves… how would living beings evolve on a planet with less gravity (like the Moon or Mars), being equal the other circumstances? We try to find out what could help us to live there and, why not, adapt to those environments. Keeping our shape? It's a challenge for Physical Anthropology from the viewpoint of Anthropometry.

## 3 The measure of man in the things

Could we find the Measure of Man in Things? In the past, Polyclitus, (Πολύκλειτος, Argo, about 450–415 BC) Marcus Vitruvius Pollio (about 80–15 BC) and Leonardo da Vinci had used geometric grids on the basis of ancient Greek canons (Κάνον), such as the ὄργυια to obtain measures and proportions for painting, sculpture and temple building design. Even though canons are based on human size and proportions, however, are merely a kind of *ludus geometricus*, an "amusement" of ruler, square and compass, lines and circles (*ludi* that were loved by Leonardo), as in Crisóstomo Martinez *Atlas Anatomico* up to the Le Corbusier's (Charles-Édouard Jeanneret-Gris) *Modulor*®.

About human size and proportions Leonardo himself wrote:

> "…delle laudabili e meravigliose cose che appariscono nelle opere della natura, è che nessuna sua opera in qualunque specie per sé, l'un particolare con precisione si somiglia all'altro… piglia dunque le misure delle giunture e le grossezze in che forte varia essa natura, e variale ancora tu. E se tu pure vorrai sopra una medesime misura fare le tue figure, sappi che non si conosceranno l'una dall'altra, il che non si vede nella natura." [1504-06 "Delle misure universali de' corpi" in "Trattato di pittura, parte terza" Leonardo da Vinci—Codice Urbinato n°1270 Biblioteca Vaticana; Francesco Melzi 1540]

Square and compass, lines and circles, wonderful works of art, perfect proportions, but certainly are not a biological reality. Effectively such artworks are, in a modern view, wonderful attempts to ideally "*design*" a Man for architecture and art purposes, not to "*comprehend*" a real Man.

From ancient Greece such "ideally designed Man" although related to Architecture, was not intended to provide technical constructions data to design. The Greek measure of length, ὄργυια derived from the human body, was the distance from extremity to extremity of the outstretched arms. It was equal to 6 feet (about 8 feet in the Leonardo's *homo quadratus*) or to 4 cubits, and was 1–100th of the στάδιον, according to William Smith W. (1874) Roman Antiquity Dictionary. The Man does not have a predefined structure or form there is no archetype in the Platonic ὑπερουράνιος[3] where the idea of proportions is deposited. Indeed following the Protagoras approach with "Man is the measure of all Things", the "project" of an organism lies in its genomic and phenotypic structure in the interaction with the constraints of the environment. Just as in the "*Teleonomic*" view of Jacques Monod: Man is an organism endowed with some kind of "*Baupläne*".

So we felt our task could be "Finding the Measure of Man in Things": in the artificial ones because the Man builds them, in the natural ones because he selects them.

To clear the concept, we feel that as the good wine has the bubbles when the Moon is right, not simply by a coincidence, but because the Farmer has rightly used the Moon as a Great Clock to cultivate the vineyard. An apple stays exactly in a woman's hand, not by the sin of Eve, but from the secular cultivator choice, so the continuous action of humans on technology and nature brought about the measure of Man in the interactive Things! As Protagoras of Abdera (about 490–420 BC) states *Of all Things the measure is Man, of the things that are, that they are, and of the things that are not, that they are not* (Mark 2012).

## 4 Evolution and Innovation

Could study the Things to find the Man's measure? In other words: Is the anthropological data contained in the artefacts? Following the trace of Luigi Luca Cavalli-Sforza and Marcus William Feldman (Cavalli-Sforza and Feldman 1981) model of physical evolution versus cultural innovation, our research aims to retrieve information about Man's physical

[3] Plato (Fedro 247), would be the seat of absolute realities, to which the best part of the human soul would tend.

characteristics through the branches of learning eminently oriented to "User centred Design" in a way to reflect the evidence of its interaction with the conceptualization of the built environment that occurs in the primary design activity when the scope of the project is drafting design features and requirements. Our approach is to recover anthropological data (physical, cultural, metrological and iconographic) contained in the artefacts considering their adaptive interactions within the domain of Ergonomic Anthropometry.

The criterion is rather complex but can be a first attempt towards our proposed concept as the "*Search of Man's measure in the Things*". In fact, if we define as "*Design*" any human activity aimed at creating new forms planned on a human scale, the anthropological and ergonomic approach to design consists in the ability to optimize the interface through secular cycles of acceptance and rejection. This way of acting is evident in every phase of human evolution and cultural development, but it seems clear since the times of the Ancient Egyptians, with the priceless examples of their *ante litteram* "design". Even better, we owe them the first anthropometric art studies for the representation of body proportions in paintings, bas-reliefs of the steles and statues.

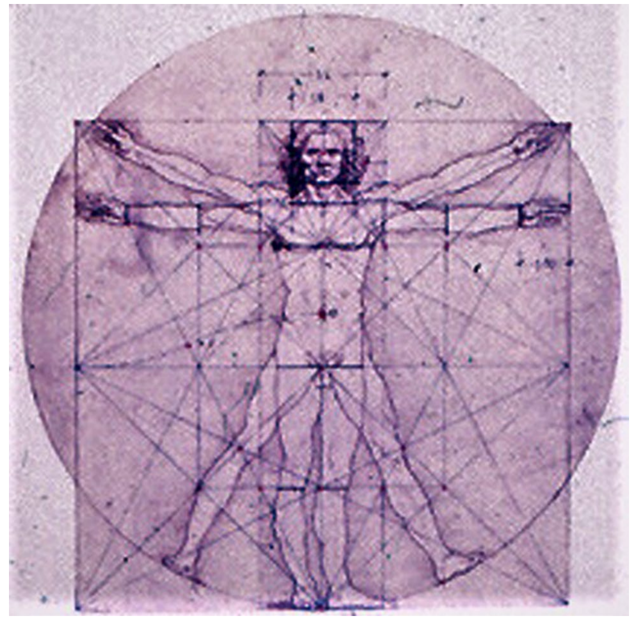

**Fig. 2** Geometric "ludi" found in Leonardo by computer. Leoni-Zambini. Courtesy of Rivista IBM

## 5 The "*geometric ludi*"

*Is the canonical man able to support the Man proportion variability?* The anthropocentric mental picture of the technological world and, sometimes, of the natural world itself, especially in Western culture, often gives us the confidence of living in a "man-sized" environment, because everything that surrounds us seems to be made by Man and for Man Design has done a lot in the field of aesthetics and functionality, but it has changed a little the anthropometric standards, even if the most innovative structures, have had a remarkable evolution in these years because the absence of codified standards has stimulated research and standardization. But which anthropometry oversees these renovations? Flicking through the proceedings of the 11th International Conference of Ergonomics (By the significant title "Design for Everybody" a first proposal for the current concept of "*Design for All*") we found only a few traces among the many recommendations on what to do and not do, but few that would clearly say what could really be done for a proper interface design. The human measures were quite vague or intangible (a gentle congress lady noted: "*using standards my gigantic mine drivers would strike their heads on the truck ceiling!*"). So we are again faced with a loss of the concreteness of the human factor or at least of the awareness of its variability and its incompressibility in "*ludi*" of any kind (Fig. 2). Our interest about the Leonardo's *ludi* has been updated on the opportunity of Leonardo's five-hundredth anniversary thanks to an optoelectronic installation within the project *Delle Misure Universali de' Corpi*: an attempt to challenge the real individual measures with the ideal Vitruvian proportions. The installation is currently operative at the "Leonardo da Vinci—Drawing the future" exhibition at Palazzo Reale in Turin. The aim is to achieve a "citizen science" experience for an anthropometric data collection on general population.

## 6 The true human measures by Anthropometric survey

*Are there real Man measures adoptable above all?* The question was open, but, at least for Italy, on the occasion of the "Ergonomics and Business Design" Conference organized by the Ancona Design Center (Pierlorenzi and Millevolte 1989) had organized a discussion to try to resolve and give a tangible structure to the question of the anthropometric dimensions to be adopted in ergonomic design, above all at national level. The problem was posed of creating an anthropometric database of the Italian population structured for ergonomic design and, in that circumstance, after a long discussion on how to overcome the intrinsic difficulties of measuring people, the idea was born to organize a survey on the beaches of the Adriatic Sea in 1990 then continued on the South Tyrrhenian shores in 1991 to have a fairly national sample.

At the work team of the Ancona Centro Sperimentale di Design, now PoliArte, were given the difficult task of creating the image of the project and the motto "L'Italia si

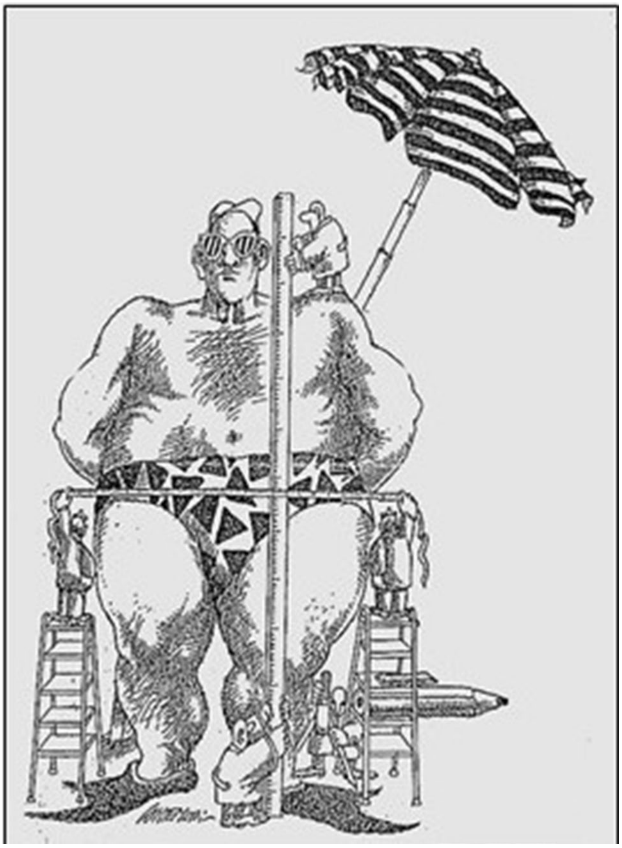

**Fig. 3** Cartoon that supported the "L'Italia si Misura" project. La Repubblica, Naples edition, 1991

misura" (Italy is measured by itself) was proposed (Figs. 3, 4). The reason of the choice of a beach survey appeared at first somewhat untrustworthy. It must be admitted that the idea of measuring people on the beaches the first reaction is the hilarity and the numerous cartoons that accompanied the articles on the subject that the newspapers dedicated to us are proof of this. Nevertheless the database was accepted as an international standard for Italy (ISO 7250-1 2017).

However, only the seaside environment allows having a willingness to be able to count on People with the fundamental requisites: availability of time, adequate clothing, and random presence (to statistically validate the sampling even if mountain climbers will probably be underestimated!). On the other hand, try to imagine drawing a truly random sample from about 55 million citizens!

At that time the availability of usable anthropometric data was still, very poor. The surveys on a national basis was almost non-existent, except for the anthropometric research of the Italian Fashion Agency (Montinaro and Nicolini eds 1979) conducted on about 15,000 subjects in developmental age (6–19 years) for which, however, the usability for an estimate on adults it was obviously limited to the last age classes, while the system of measures reflected the necessities of the clothing industry and, therefore, not necessarily, the parameters for the ergonomic design that were then being defined. In fact, also in accordance with a methodology just developed (Grieco and Masali 1972) (Fig. 5) and put into practice in the field at a large Milan Rubber Industry with a first survey on a male population (70% North, 30%

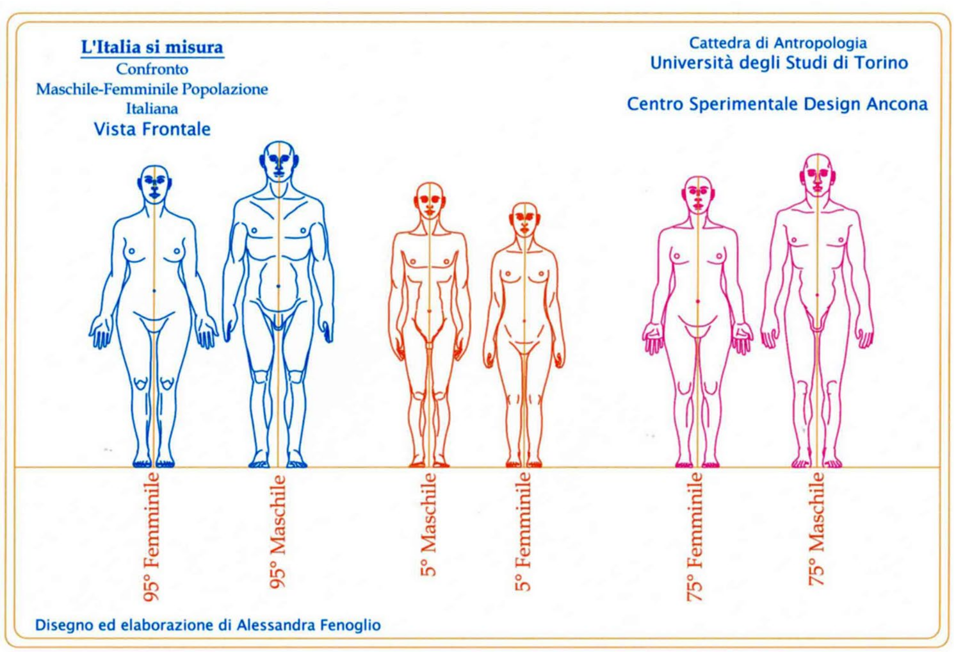


**Fig. 4** Example of morfosomatotypes obtained by clustering "l'Italia si misura" anthropometric data. Drawing by A. Fenoglio, clustering by Salis (1996)

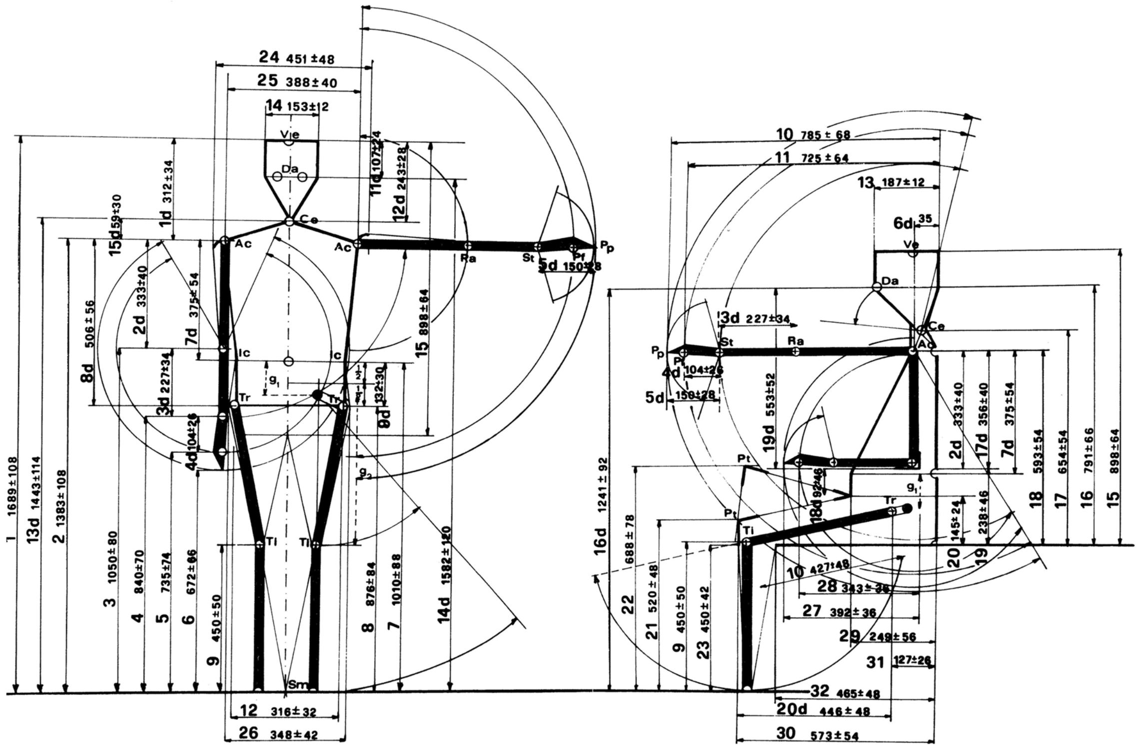


**Fig. 5** Drafting board Anthropometric mannequins (Grieco and Masali 1972) conceived for human-system interface design. Also published in Labour safety Encyclopaedia, Bureau International du travail, Geneva

Center-South) had allowed us to build a first graphic mannequin (Locati et al. 1977). It was then possible to test the application of the method on rubber mixing machines and it was possible to detect a first female sample (Soleo et al. 1980).

At that point we were ready to start a first nationwide survey specifically for ergonomic design. The problem was that of being able to carry out a survey on the generalized population and not only on samples of an industrial environment which at that time were still affected by the selective effects by the type of work and the hiring visits. The concept still prevailing was yes to put the right man in the right place, but the criterion was rather to adapt the man to the task and not vice versa.

Being available, the anthropometric measures of the human population to which a research project can be directed; let's see what "ludi" we must look at. The most common, but also now fully exceeded, is simply the use of averages. Researches (Coniglio and Masali 1990) carried out with the method of *k* means analysis put in evidence what anthropologists and constitutionalists had always affirmed: the larger or smaller subjects are not representations in scale of the "Average Man". Scaling the "ideal" proportions of the Vitruvian Man is reflected in the largely outdated theory of the Average Man by Adolphe Quételet (1835) according to which within a given human group the average value of each character could be chosen as a "typical dimension" that defines the group. The average value of each anthropometric variable defines in the set of quantifiable characteristics a coherence that is perceived and converges towards a representation of a "ideal" person, but which in itself does not exist.

## 7 Ergonomics and "user centred design"

*Is Human Factor able to use the real Man measures?* "Ergonomics or Human factors deals with understanding the interactions between human beings and other elements of a system, and is the profession that applies its theoretical principles, data and methods to design to optimize human well-being and the overall performance of the system" (www.iea.cc, 2000). Truthfully, Ergonomics does nothing but formalizing the capacity, present since the first representatives of the genus *Homo*, to build objects functional, but also suitable for the user. It is appropriate to remember the figure of *Homo* "*faber*", in the conception of Luigi Bandini-Buti, one of the fathers of the Italian Ergonomics Association (SIE), as "producer of the tools for himself, which brings together all the knowledge necessary to achieve the purpose and naturally works the synthesis during the conception and the production of the instrument: humans know by direct experience the use to which the object is intended, the user who is himself, knows and is immersed in a culture widespread using his experience and that of the others" (Bandini-Buti 2008).

## 8 The role of anthropometry or "human measure"

Anthropometry is aimed at evaluating the quantitative aspects of the human body, in its biological and in particular biometric characteristics. Commonly the anthropometric knowledge is achieved through direct or optoelectronic measures; nevertheless a different approach may be to infer the dimensional, or morphological, characteristics of the body from the analysis of objects that interweave with the user. Referring, by antilogy,[4] to the sophist Protagoras, this attitude and approach can be summarized in the expression "The search for the measure of Man in things", which we proposed (Masali 1994). Considering our anthropological background, our first attempt to attain information for an anatomical explanation of an "indirect anthropometry through the things", was, therefore, tried in the field. From this viewpoint indirect source information on body size, are as well as the artefacts that come from the past, but also their artistic representations (Marro 1927). The initial stimulus of this research was for us some infinitesimal differences in the "design" of the "leg extenders" typical of early Egyptian chairs in funeral portraits.

## 9 Proto-ergonomics

The argument of the research originated from the reporting of chairs design diversity detected in the paintings of the Chapel of Maia, now in the Turin Egyptian Museum. Such funerary "chapel" was discovered in Deir el-Medina, in February 1906, by the Italian Archaeological Mission of Ernesto Schiaparelli. The archaeological site was the village and the cemetery of the workforce employed in the Valley of the Kings area reserved for royal tombs of the capital, Thebes (Egyptian Uaset, transliterated:W3st). The paintings, detached with the technique of the tear, were reconstituted in Turin in the original provision. Careful observation of the chairs on which sat Maia and his wife Tamit showed differences in the thickness of the *"leg extenders"* adjustments set under the lion paws of the seat (Fig. 6). Their function was

**Fig. 6** Chair leg extenders under the lion paws. (copyright photo® by Nicola Dell'Aquila and Federico Taverni, Egyptian Museum of Turin)

clearly to adapt an artistically designed chair to the human figures *popliteal* height keeping the chair aesthetics proportion. Perhaps the different height is merely dependent by the feeling of the painter, but it may be influenced by the instinctive perception of the so called *"hidden dimension"* and gender dimorphism. Even if it may seem a negligible the question of the real existence of any mode of "*adjustment*"[5] of the chair according to the *popliteal height* gender dimorphism (not so marked in Egyptians as suggested by Masali and Borgognini Tarli 1983) we proposed an enquiry to investigate their "proto-ergonomic" assessment. The issues raised were referred to the definition of a larger project aimed at identifying in the Egyptian civilization, those principles of cognitive anthropology, which every ethos entrusts its cultural message (Masali et al. 2014).

## 10 Perceptive anthropometry, proxemics and interspaces

Trying to understand and correctly design the human-system interface, an important topic of anthropometric enquiry is the search for the "hidden dimension", to say it with Edward Twitchell Hall (1966) that is, borrowing the concept from Proxemics, the management of the anthropometric space (Pregnolato-Rotta-Loria 1998) visualized by the dimensions

[4] Contradiction of ideas and terms (from the gr. ἀντιλογία "contradiction", comp. of ἀντί "against" and λόγος "speech"). In the Greek skeptics, opposition of two mutually exclusive theses. In the modern age, from Kant onwards, the term has been replaced by antinomy (Enciclopedia Italiana Treccani: Dizionario di filosofia 2009).

[5] Leg extenders layers were absolutely common in most Egyptian paint and existing furniture.

one attributes to himself on the basis also of ethological or cultural behaviours as well as the "interspace" between user and the system (Masali et al. 2009). In this field, the interface can be largely modified by the way in which the humans interact with the technological object engaging the spaces within the body and the structure. It, therefore, seems that alongside the anthropometric record, the mannequins and the virtual simulation instruments that are now crucial for a correct ergonomic design, should be taken into consideration in the relationship of the specific ethological-cultural moment and also the intercultural or alter-cultural situations that may characterize the use of an artefact at different times and in different situations.

## 11 A planet for humans–humans as an earthly tailoring process

Sometimes, like Voltaire's Candide, written in 1759, everlasting optimist Docteur Pangloss (Voltaire 1991) we believe living in the best world in the Universe. The concept is often put into the form, "everything is for the best in the best of all possible worlds" ("*Tout est pour le mieux dans le meilleur des mondes*"). Optimism may be founded on the Gottfried Wilhelm Leibnitz's (Leibnitz 1710) "Theodizee". Nevertheless, the reality is that we are fully "adapted" to a unique planet and we should have no reason to be optimist as water eutectic band planets may be extremely dispersed in the Galaxies, with practically no chance to colonize another one.

Adaptation means evolution; nevertheless in this domain, the question of adaptation to new, unexpected environments (without attaining the border of extinction) appears quite unsolved. Adaptation requires extremely long times, and involves the architecture of the whole organism, even when a specific trait is involved. In the theory of evolution, Charles Darwin posed the question of how organisms could afford new environmental conditions. The concept, still convincing, has been developed in over centennial debates and new concepts such as "*Evo-devo*" (Evolution and development), "Modern synthesis", the mechanisms that generate selectable variation. The origin of phenotypic complexity, the tempo and patterns of phylogenetic changes and several other issues related to adaptation such as plasticity or self-organization are the themes of debate (Harrison Matthews 2008; Fusco 2019). These complex events occur when a species or population has characteristics that are suited for conditions which have not yet arisen.

Suggesting that Darwinian "*Pre-adaptation*" connoted foresight, Gould and Vrba proposed a new term "*Exaptation*" (lat. *ex aptus*). Stephen Gould and Richard Lewontin (Gould 1991; Gould and Lewontin 1979) argue (with a bit of humor!) that the traits of animals (their body and behavior) may have developed for the same reason as "spandrels". A

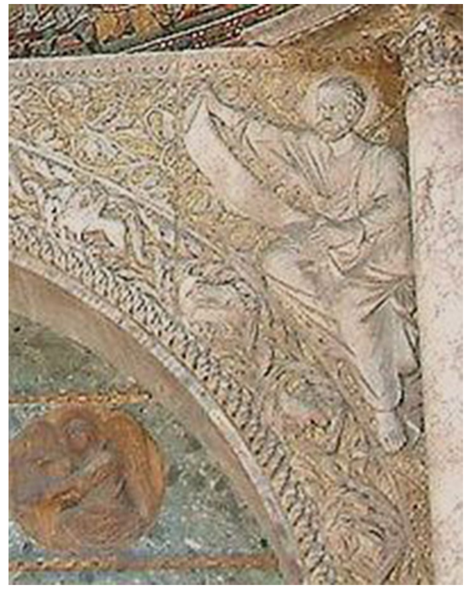

**Fig. 7** A "spandrel" or pendantif. Courtesy of Reverenda fabbrica di san Marco©, Venice

*spandrel* (Buss et al. 1998), like the pendentifs of Renaissance domes, provides a blank area between two arches that may be useful for artists to exercise their imagination (Fig. 6). However, a cathedral was not built with curved arches to leave spandrels that could be decorated, but for architectural prerequisites. As spandrels arise because of an architectural constraint, these 'spandrel traits' are consequences of true adaptations that actually evolved under the pressures of natural selection (Fig. 7).

In extreme environments, adaptation there is no time to evolve, so the spandrel pathway may be a possible approach. So, how may adaptations arise according to the current evolution doctrine in the domain of the Outer Space ever since the available time for adaptation is insignificant?

## 12 Outer space human adaptation

The levels of habitability and performance in Space and Extreme Environments are closely related to the human capacity to integrate and adapt to a specifically premeditated technical interface design, or simply *human–system integration*. The main goal is to create a system able to respond to the human needs. Of course, we know that a well-designed habitat and a mission with a good habitability "*can decrease the probability that the environment will contribute to crew error or other performance issues*". However, "*in the case where the environment cannot be adapted to the human, research indicates the human does have the ability to adapt to the environment*" (Novak 2000).

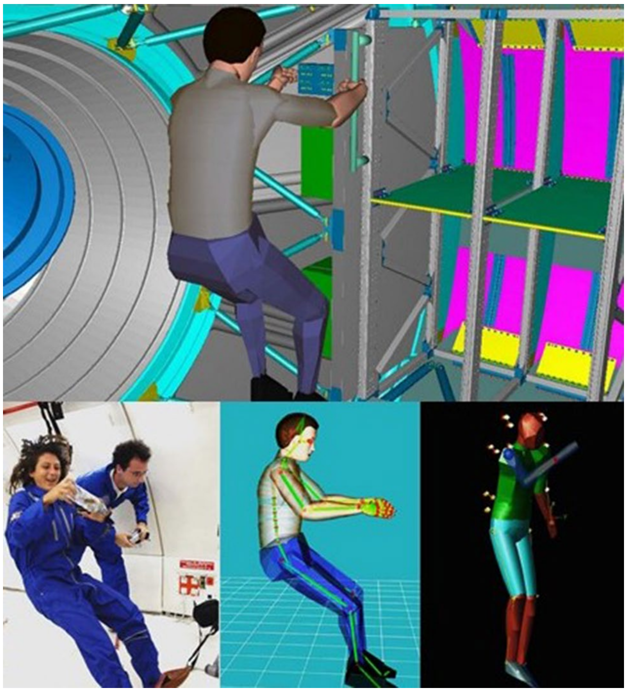

**Fig. 8** 3D simulation to test human interaction on a Space Module, co-author Irene Schlacht in 0g posture in 2006 parabolic flight, Jack® mannequin and optoelectronic ELITE® posture analysis (Courtesy of Thales Alenia Space, Turin, within the "Real Man project")

Human adaptation can be achieved with selection and training of the crewmembers, artificial adaptation and, we may today suggest, by natural Exaptation (Schlacht 2012). The countermeasures may come across selection and training: humans are integrated into the system through selection and training protocols, while artificial adaptation occurs when the system is designed and adapted to support human needs, while exaptation occurs when the body naturally reacts to the new psycho-physiological constraints exploiting in a new mode the natural traits that are positive for the human-system integration. Without to forget that to live in Outer Space, humans again need to adapt and evolve with completely different environmental conditions (Masali et al. 2010) (Fig. 8).

## 13 Selection and training in a space adaptive perspective

Astronauts and Cosmonauts are selected on the basis of their characteristic ability to best react toward the psycho-physiological constraints in Space and are trained to improve their potentiality to be productive under those constraints. In the NASA SSP 50005C (1999) report, selection and training are part of the human-system integration study so as "*to form an effective Human–Machine System*". Selection and training are particularly important and apply both to the physical and psychological levels. For example, as elucidated by Sonya Ongaro (2005), the main focus of the psychological training should be on self-management, leadership and teamwork, and group living. Those aspects affect habitability, particularly at the social level.

In the past 50 years of the space age, selection has been based on aptitude. The Fédération Aéronautique Internationale (FAI) defines spaceflight as any flight ahead of 100 km from the Earth's surface. Following this definition, up to 2011, there were only 520 astronauts in total, only 24 of whom have traveled beyond low Earth orbit and of who 12 have walked on the Moon. Six of the 520 were space tourists, and two were commercial private spacecraft astronauts (Anikeev 2011), little samples for statistic protocols! Moreover, many professionals and students among which one of the coauthors of this article (IL Schlacht), experienced sub-orbital 0 $g$ flights with simpler fitness medical check. This means that only two of the 520 astronauts were outside of the agencies' aptitude-based selection.

How can these humans adapt to the Space extreme environment apart from attitudinal selection? One option would see the physical integration of technology with the human body to approach extreme environmental conditions, to create a new "cyber" identity that transcends the boundary of "the relationship between inner space to outer space" (Halacy 1965). Indeed, a cyborg, or a human being with an integrated machine, was intended by Clynes and Kline (1960) to support extra-terrestrial exploration: "Altering man's bodily functions to meet the requirements of extra-terrestrial environments would be more logical than providing an earthly environment for him in Space". However, ethical constraints must also be obeyed since astronauts need to represent humanity in its integrity, as underlined by Prof. Ernst Willi Messerschmid et al. (2009). If the human being is "taking an active part in his own biological evolution" (Clynes and Kline 1960), allowing himself to be artificially modified or manipulated with genetic engineering to fit in with the extraterrestrial environment, then this may obviously end up in a new species…! Ultimately, Cyborgs appear as a "useless" human manipulation to fit something that is already adapted, but ultimately a bit of trouble we would have to inhabit the Moon.

## 14 Ergonomics, shape anthropology and space

Living in Outer Space has recently inspired a vast literature in the fields of space technology, medicine and psychology. As humankind faces peculiar environmental conditions affecting locomotion, working capabilities and general living, new forms of biological and socio-cultural adaptation are likely to occur. This represents a big challenge for the studies of our species. Since good interior design and interface usability depend on human characteristics that are modified by variations in the environment, is felt the urge to re-think the whole concept of human *"well-being"* (Burzio et al. 2003; Ferrino and Gaia 2003). In a spacecraft, body shapes are modifying, reflecting the human variability, and also the physiological adaptation to zero gravity. In the experience of space stations, from the Salyut orbital stations, to Cosmos, Skylab, Mir and the now orbiting ISS Alpha, everyday objects, such as toothbrushes may be lost due to the visual chaos and the lack of 'up-and-down' references.

During long space missions in micro-gravity, social interaction is constraint in small group, and astronauts have to deal with psychological stress and difficulties in communication. Concepts such as power and gender, strictly linked to the human bodies and their symbolic and physical functions, are going to change in a place where gravity may be counterbalanced. Within the Space domain, physical and cultural anthropology seem to belong to a less exploited field. One exception is anthropometry, limited to its strict meaning: the measure of man, say: the astronaut. Within the studies of bodily form in Space, the neutral posture was defined, *inter alia*, by the experiments about the human posture in microgravity. Results confirm the excellent metamorphosis capability of motor arrangement by the central nervous system to best exploit environmental constraints. Moreover, the system allowed constructing anthropometric mannequins with 'Jack'® computer graphics as an important topic of a 2003 Space reseach project "Real Man" devoted to the study of an integrated technology for the dynamic simulation and advanced visualization of human virtual environment.

Our cooperation, albeit limited to the anthropometric method to measure the astronaut and the provision of an Anthropometer has enabled our team to get to the heart of the problem by stimulating the search for behavioral archetypes present in humans.

One of the focal points of our inquiries (as a part of the Extreme-Design research team) was aimed at the study of body movement, orientation and posture that are stoutly influenced by gravity. Our hypothesis is that if the gravity decreases, the body loses the 'upright posture' as vestibular reflexes less enforces it, and converges to the 0 *g neutral posture*. Consequently, in microgravity the ground point at which the view is aimed should be closer. Although there is 'no difficulty walking', as stated by astronaut Neil Armstrong, the difference of gravity on the Moon affects the upright posture and suggested astronaut Buzz Aldrin to test methods for moving around, including two-footed kangaroo hops. Which, perhaps not incidentally, reminds us the walking of some Lemurs who keep on the soil the upright posture acquired in the forest by their arboreal vertical clinging (Napier and Walker 1967; Torres and Mueller 2001) (Fig. 9): another exaptation? Nevertheless, on the Moon the

**Fig. 9** Lemur Indri in the jump take same posture than man in "neutral position" in 0g. (foto by Viviana Sorrentino®)

angle of view generated by vestibular reflexes can be titled more toward the soil (Fig. 10). An image of astronaut Edgar Mitchell (Apollo 14) confirmed by the posture of astronaut Aldrin (Apollo 11), gives us proof and perhaps, prudently, we may measure the effect.

Microgravity changes the movement and the orientation capacity in a complex of issues (Pizzigalli et al. 2013; Tinto et al. 2012) as evidenced by the French choreographer Kitsou Dubois: gymnastics and dance can be performed in little or no gravity, offering a new opportunity to develop the study of human movement when highly formalized with optoelectronic techniques (Bureaud 2009). In our opinion, the complexity of such kind of extreme physical activity, strongly related to gravity may give a wide opportunity for studies when deprived of its major parameter: weight.

## 15 An improbable task: building a new man

The main question that arises is whether the solution is adapting humans or, in the near future—say the next 10,000 years in an evolutionary perspective—even considering (Voight et al. 2006) some very recent positive selection observations about the adaptation of modern humans to local conditions, is adapting the environment to humans. Earth's mimicry of vital parameters and life environment, should be mostly obtained with a careful design of outer space crafts, both vehicles and planetary living structures according to human factors and ergonomics principles (Schlacht et al. 2008, 2009, 2016a, b) The task is to design the structure to maximize human well-being. Such tasks may be complicated but still possible for air, warmth, water, waste and food and, still not solved, radiation protection. Gravity is the real difficulty; unless space designers should build something like the Spacelab squirrel-cage track or other types of devices to simulate weight. However, living

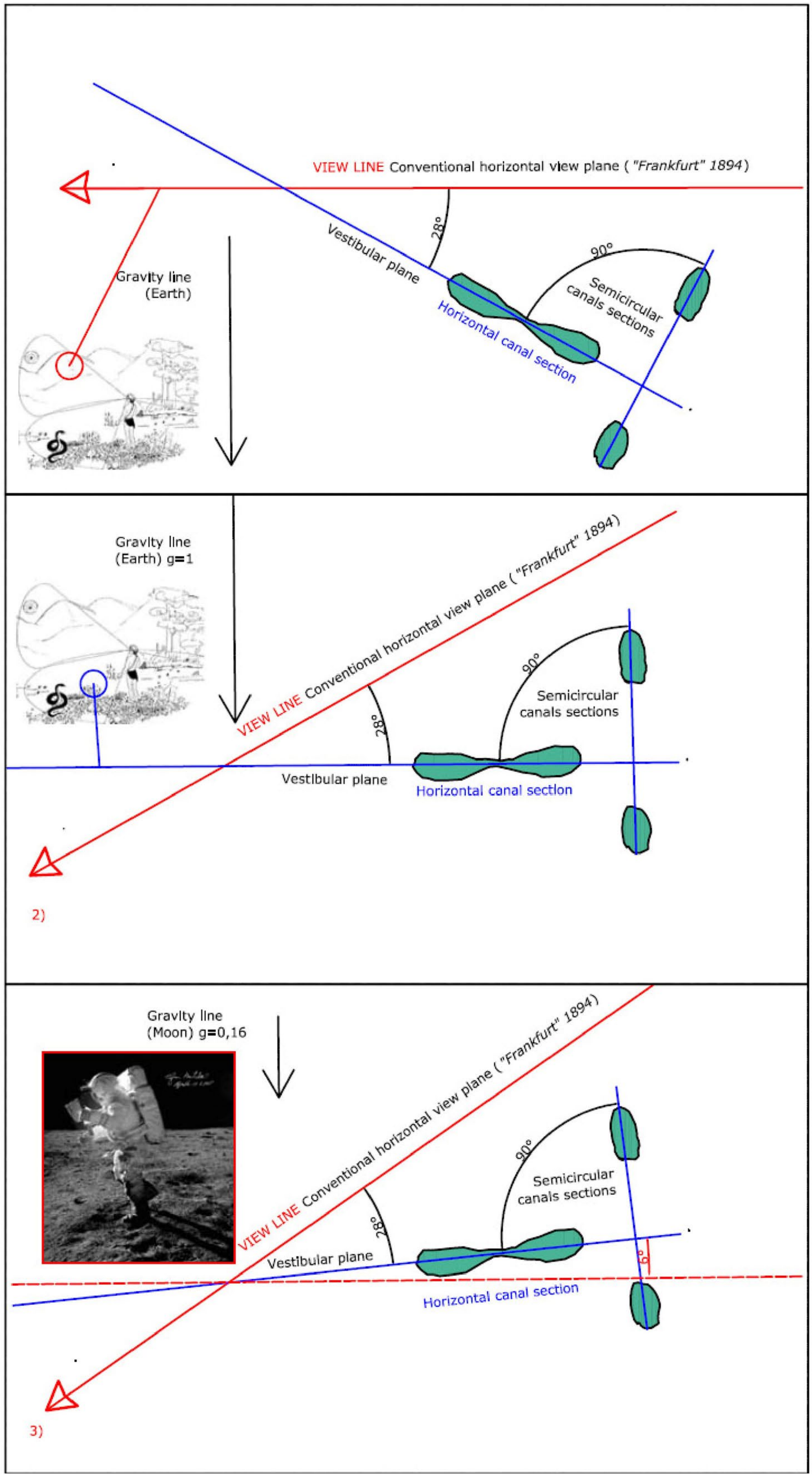


**Fig. 10** Interpretation from the temporal bone semicircular canals sections oriented in traditional "Frankfurt plane" (*Ohr-Augen Ebene*), top, Vestibular plane, centre, and, tentatively, on the Moon microgravity (1.62 m/s$^2$)

in a centrifuge on spacecrafts requires a continuous engine thrust to generate weight by acceleration. Then gravity, the human form-mould, remains in actual fact the hardly solvable human factor. At last, trying to understand the outcome on genetics, morphology and culture that aptitude selection may affect the future space human, the risk is to create a new human isolate population, something like has been observed ongoing on a Caribbean workers/climbers group that operates at high altitude particularly in the Italian Dolomites in a Moonlike landscape. Maybe another 'bottleneck effect' (Argenta 2008).

## 16 Human variability on Earth and Space

The study and knowledge of human variability in its dimensional, physiological, psychological or socio-cultural aspects is as important today as it was in the past and really contributes to be applied in various contexts of life and work through the adaptation of the artifacts to the differentiation in time and space of human characteristics and needs, pursuing wellness. The goal is more and more improve interaction with the system more and more, therefore, not only "on a human scale" but "to the measure of human variability" and of its becoming.

Anthropometrics research has recently been able to renew its aims and methods, making use of important technological innovations (in the context of an "Anthropology 4.0"). Today, for example, the use of three-dimensional scanners is increasingly common for the detection of anthropometric variables but also for the creation of virtual mannequins. Total body scanners are applied to generate anthropometric databases, on a national and international basis, useful to match clothing sizes to the becoming of populations and to market globalization (Size Germany, Size Italy, etc.). Three-dimensional surveys are also performed using simple and low-cost tools (Kinett applications) that in all cases allow basic measurements of human body variables and some three-dimensional evaluations for different purpose (Bragança et al. 2018; Clarkson et al. 2016). Today the technology also produces valid and reliable video systems and software to perform motion and postural analysis for detailed analysis of the movement in sports and work contexts (Elwardany et al. 2015; Micheletti Cremasco et al. 2019a). Research projects are characterized by wide interdisciplinary expertise involving private companies and research institutions operating in different fields for anthropometry, biomechanics and industrial ergonomics. Studies that also use wearable sensors for postural evaluations (Plantard et al. 2015; Dahlqvist et al. 2016) and perform virtual simulations in 3D of work activities for the design of production lines and individual jobs. Nowadays, interests in design coexist in applied research that really takes into account the maximum possible variability of users in the perspective of *Design for all* but also studies aimed at a few for truly "tailor-made" design for the single person or for a few. Considering particular sectors such as the agricultural one in relationship to the problems of adaptability and safety in the use of machines and equipment, studies are carried out on the physical-functional characteristics of users of specific contexts, at the extremes of bio-socio-cultural variability, with analyses aimed at identifying specific needs and to contribute to specific corrective planning of the system with which that type of user interacts such as migrants and agricultural old workers (Caffaro et al. 2017, 2018a, b, c). Also in this sector, the use of sensors placed on subjects shows important perspectives of analysis of human movement in relationship to the means and to the problems of postures and movements in safety of the operator.

The study of anthropometric variability on large and consistent samples is of interest also for large companies oriented to the improvement of human interaction in the course of activity in productive contexts. Knowing the national variability of operators in the production area makes it possible to design workplaces, protection devices, production lines that are more "suitable" for operators. Also in these cases, the study of anthropometric variability leads to the knowledge of the need to regulate the elements of the system and improves the design with usability tests carried out by subjects who really represent the percentages of measured variability and these tests are also carried out in situations of virtual reality increased (Micheletti Cremasco et al. 2019b). Even for simulations, requests for "real" data are increasingly frequent to implement three-dimensional mannequins that are able to simulate ever more faithfully the human interaction with the system being assessed/designed (Plantard et al. 2015; Bosch et al. 2016).

## 17 Closing assumptions

Space, selection, migrations may substantiate the "Bottleneck" hypotheses that tries to describe the effect of small founder groups of present wide population: there is a strong consensus that modern humans originated in Africa and moved out to colonize the world approximately 50,000 years ago (Amos and Hoffman 2009). During the process of expansion, a great amount of genetic variability was lost, creating a linear gradient of decreasing diversity with increasing distance from Africa. However, some essential traits (just to say: skin color) were dramatically improved. The exact way in which these events occurred remains somewhat unclear: did it involve one, several or a continuous series of population bottlenecks? Could the events be associated with exaptations? Are we facing one more in Space, with a reduced biodiversity and increased co-optation of special traits? It seems a contradiction; nevertheless few key genes with high fitness in the new environment may lead the

**Fig. 11** Vertical Treadmill of DLR© DLR (courtesy of Prof. Jörn Rittweger)

exaptation process so that the new population may appear widely different from the original. Shmith (2013) proposes something like a new species (*Homo extraterrestrialis*). We rather believe that instead of a *Homo novus* (Masali 2010) there will be a human, maybe with a different look, but only a fragment of terrestrial heritage. To people the Moon will be a high selected population with very limited genetic heritage starting by a highly selected group of astronauts.

## 18 ZEROg (microgravity)

The main goal of this specific research was to discover the relevance of the gravity as variable that influence the Man measure for the Human Factors Design in Outer Space and on Earth. In our Laboratory of Anthropometry and Ergonomics at the University of Torino, during 50 years Physical Anthropology, Anthropometry, and Ergonomics researches have been conducted not only to study past and present human populations, but also to deduce the potential expectations. In the specific case the Outer Space has been approached as one of the possible future extreme element that the human technical, socio-cultural, and genetic evolution will approach…in this precise case the most extreme. In this context, human measures acquire a strong changing because the human physical body and overall perception is completely modified by the difference of gravity. For example in microgravity the neutral posture change the human dimension of height, as well the microgravity affect all the organ of perception (visual, auditive, tactile, haptic, etc…) and as a consequence the perception of measure.

A wide area of interest about the relationship between humans and system in microgravity developed in the last 62 years, the "Space age". For the first time humans experimented real microgravity thus increasing the need to better understand and address human behavior walking and balance on the Moon and Mars in the design for long duration missions. A number of studies already exist on simulation of hypogravity locomotion (Fig. 11), but how we can use results from hypogravity simulation studies to inform the architectural design of Moon or Mars habitats. To better understand human behavior, particularly in walking, one key factor to consider that is addressed here for we can climb, but we can also easily lose our balance and trip up against the surrounding architecture. The first time is the effect of deconditioning and the countermeasures applied to the subject to decrease this deconditioning. Once these factors are under control, the data needed for defining the interior design are kinematic variables of joints or body segments, such as speed, step extent, direction of movement, sight line, variation of altitude, typology of walk, posture, and balance. Finally, the data need to be communicated in an interdisciplinary manner using a common language between the physiological and design fields. The ideal research methodology is presented here, which investigates how to measure and share variables of gait and body movement to apply the results to the design of Moon and Mars architectures. Motivated by these preliminary observations, in 2009 part of this group of researchers investigated human movements and balance in Moon gravity. The research—conducted using images and videos from NASA's Apollo missions—shows that when we walk on the Moon using one of three modalities—modified walk, hop, side step– the different walking patterns have an impact on the visual field. In particular, the head is tilted more downwards; as a consequence, our eyesight is lowered and we see a narrower visual field. This could, for example, reduce the perception of obstacles and decrease our balance. In other words, while we walk, we cannot see so far, which makes it more difficult to avoid obstacles and increases the possibility of tripping up. Our balance is usually supported by the vestibular system; however, this could be affected by hypogravity just as it happened in microgravity. In particular, in microgravity movement orientation is based only on the visual system. In the case of the Moon, even the visual system will not help us that much. Indeed, if we consider EVA (extra vehicular activity), the desert of regolith on the Moon does not have so many references that will allow us to build up our up and down orientation based on our visual field.

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**Ethical statements** This paper implies no specific bio-medical, or anthropometric action, or sampling on humans and animals. Cited research and related images refer to studies completed and published in the past and may have then concerned informed consent to anthropometric measurement and medical fitness examination for 0 g flights.

**Conflict of interest** The authors declare that they have no conflict of interest.

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