THE FUNDAMENTALS OF BIOMECHANICAL MODELLING IN TRANSPORT FACILITIES

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Summary

The fundamentals related to biomechanical modelling have been discussed in this paper from the engineer's point of view. The paper is a kind of review and it is to present various biomechanical modelling methods used to study the phenomena taking place in transport facilities. Reference has been made to the history of development of the modelling, with directing particular attention to the beginnings of the modelling. Definitions of the term "model" have been quoted and various model types have been discussed. The idea of "biomechanics" has been defined. The method of building a model of the human body has been shown. Attention has been drawn to the major segments of the human body from the point of view of taking the segments into account in the modelling process. The difficulties challenging the modelling of body movements and forces acting on the body have been described. The classification of biomechanical models has been presented, with the characteristic features and examples of application of such models having been described. Various types of biodynamic models, including physical, mathematical, and animal models, have been pointed out. Differences in the modelling of a human body depending on the model adopted have been highlighted. A number of modelling examples have been presented. In the conclusions, it has been emphasised that a specific biomechanical model may represent only a few aspects of the human body. On the other hand, model validation should include comparisons between the predictions of the model and independent observations of the predicted responses. Directions of further work on the modification and development of models have been recommended.

Keywords: modelling, biomechanics, biomechanical modelling, transport facilities.

1. Introduction

The idea of "model" began to develop simultaneously with the development of cybernetics, control theory, and informatics. With the development of mathematic machines, it found wide application in the simulation and modelling of various processes. In 1945, Norbert Wiener defined "model" as "representation of a process or system (actually existing or planned for implementation), where important characteristics of the process or system are expressed in a usable form" [1]. In publication [2], the following definition of "model" has been given: "A system that is to imitate specific features of another system referred to as the original." The definition given in book [3] has been formulated from another viewpoint: "A model isomorphic with a phenomenon investigated in terms of machinery dynamics and taking place in a system under consideration should be understood as such an idealisation of the system modelled that, when selecting the features considered most important and ignoring the others, one may obtain, at identical inputs applied to the original system and its model, outputs from the model and the original system sufficiently close to each other."

The following model types may be distinguished [1]:

1) Conceptual, where a logical proposal of putting important features of a process into order is represented;
2) Physical, where important features of a process are interpreted in accordance with the physical nature of the process (the physical model is understood as a faithful but scaled-down replica of the process or system under consideration);
3) Mathematical, where the model features are represented in the form of mathematical relations (the mathematical model is understood as a set of mathematical relations describing the system).

There are also other types of model classification [1]. A model may be "structural," if it includes separate models of system elements and relationships between them, or "aggregated," if it represents the system as a whole. A model may also be dynamic or static, linear or non-linear (with the non-linearity having geometrical or physical nature), deterministic or stochastic, etc.

A similar model classification system (in terms of machinery dynamics) has been presented in book [3]. The model types distinguished there include, as previously mentioned: physical model, representing the system to be studied and the phenomena taking place in this system; mathematical model, being an analytical description of the phenomena covered by the physical model; structural model, where the internal arrangement of a model is similar to that of the system under consideration and where just mutual similarity and correspondence take place between the model and system elements; and functional model, where the model must only satisfy the requirement that the system and model outputs produced in result of identical inputs having been applied to the original system and its model must be sufficiently close to each other, with the internal structure of the system being disregarded. That model classification system also includes models that may be discrete and continuous as well as linear and non-linear.

A model is a kind of simplification or idealisation of the system modelled. The degree of conformity of the model to the original system should be sufficiently high that any conclusions concerning the system but based on simulation tests of the model could be considered true. No general recipe can be formulated for model construction. However, some methodical hints may be given in the case of models built for a specific purpose.

A model should be judged not in terms of what it claims to predict, but how well it predicts what it claims to predict. Hence, a simple model that makes a specific claim may be "better" than a complex model. The simple model may be advantageous in the following cases:

a) It makes a more specific claim;

b) Its accuracy of predicting what it claims to predict is better than that of a complex model.

It is misleading to offer a model without clearly specifying what it claims to represent and, therefore, what it actually does not represent. The claims may relate to:

- model form;
- model parameters;
- conditions over which the model may be used;
- applications of the model; and
- model accuracy.

On the one hand, it seems obvious that a model should not be proposed without declaring the evidence on which the model is based; on the other hand, not all models are derived from rigorous scientific work. A model should be linked to evidence related to the claims inherent in the model and its proposed application. The evidence should not be restricted to that in support of the model but should be a fair representation of the prevailing knowledge. The information should be sufficient for a user of the model to investigate whether the application of the model is likely to be useful.

From a specific point of view, as it has been noticed by the author of [4], the prefix "bio" in model names is often abused because in most cases, the models presented have concentrated parameters and they are mechanical models of the human body (or even simple linear models, e.g. [6]) and do not reflect complex biological functions. Even dynamic models of the "mass-spring-damper" type are used. An example is [26], where the impact of general vertical vibration on the human body was considered.

Models find particularly wide application in examining problems generally related to mechanics (dynamics).

2. Biomechanical models

As it is in mechanics, models are also built to study the phenomena that take place in the human body. In this case, the mechanical model of a human body is understood to be a mechanical system consisting of elements with concentrated or continuously distributed masses, where the mechanical impedance or transmittance of the system is in conformity, according to a specific criterion, with the impedance or transmittance of the human body determined otherwise [4]. In terms of mechanics, the human body may be treated as a continuous elastic-damping system. Such a system may be simplified by replacing it with an equivalent discrete model with many degrees of freedom. Fig. 1 shows the major segments of the human body. An example of taking the segments into account in the modelling process is presented in Fig. 2. In turn, an example of modelling a person seated in a vehicle and a discrete mechanical model of such a person according to [4] are shown in Figs. 3 and 4, respectively.

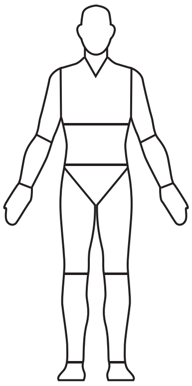

Fig. 1. Major segments of the human body.

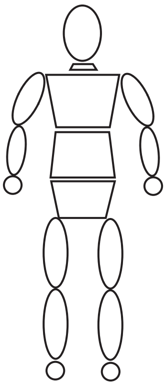

Fig. 2. Example model of the human body.

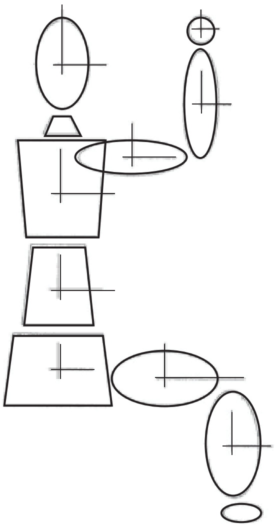

Fig. 3. Example of the modelling of a seated human body [4].

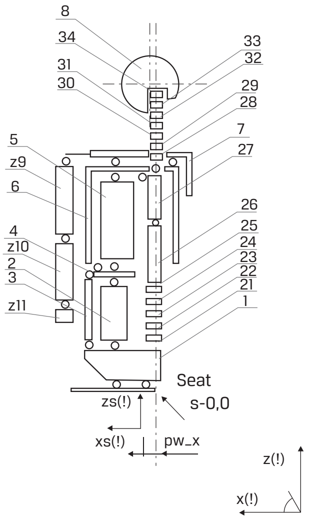

Fig. 4. Discrete mechanical model of a seated human body [4].

In Figs. 3 and 4, not only the human body segments have been modelled in a different way but also the numbers of the body segments adopted to build the model are different. In Fig. 4, individual members and parts of the human body have been denoted as follows: 1 = pelvis; 2 = internal organs in the abdominal cavity; 3 = abdominal teguments; 4 = diaphragm; 5 = internal organs in the thorax; 6 = thorax; 7 = shoulder girdle; 8 = head; z9 = equivalent arm; z10 = equivalent forearm; z11 = equivalent hand, z15 = equivalent thigh; z16 = equivalent shank; z17 = equivalent foot; 21,22,23,24,25 = five lumbar vertebrae; 26 = lower part of the thoracic spine; 27 = upper part of the thoracic spine; 28, 29, 30, 31, 32, 33, 34 = seven cervical vertebrae.

Another example of discrete modelling of a seated human body is presented in Fig. 5 [5]. Here, the model identification method based on tests carried out on a special test stand have been presented. Examples of other studies on the modelling of a seated human body can be found in [6], [7], and [8].

Fig. 6 shows an example of the modelling of a pregnant woman seated in a vehicle [9]. Here, a new "element" of the model, i.e. a child in mother's abdomen, can be immediately seen. In comparison with the preceding examples (Figs. 3, 4, and 5), we can see here one more model building method (another form of modelling the spine, arms, or torso). In this case, let us note that the authors neglected legs when modelling a seated human body. Other example studies on this subject have been reported in papers [10] and [11].

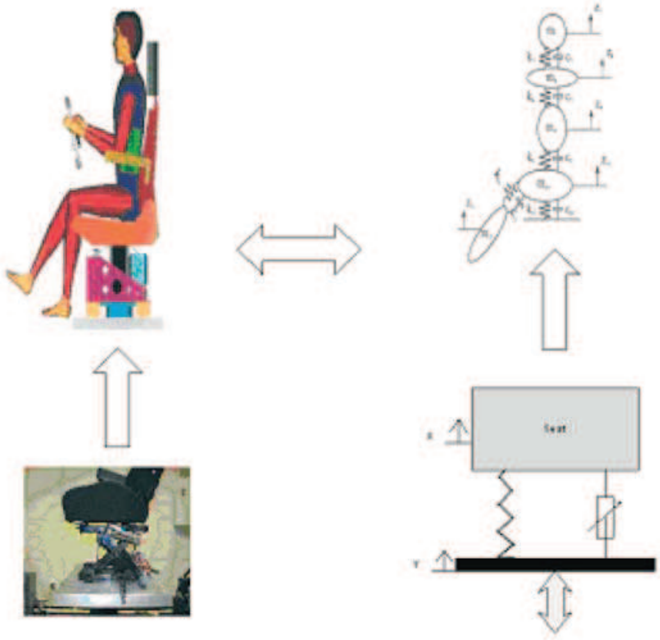

Fig. 5. Schematic diagram of discrete modelling of a seated human body [5].body [4].

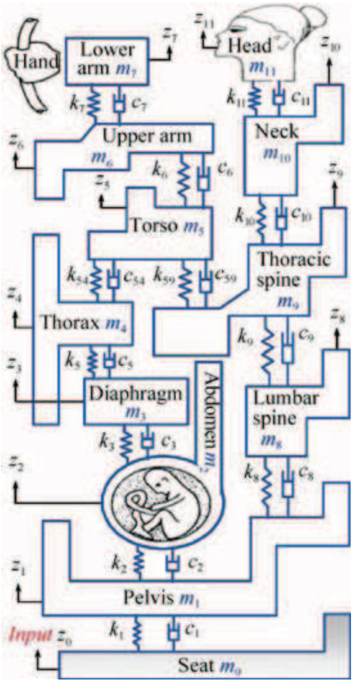

Fig. 6. Mechanical model of vibration of a pregnant woman [9].

It is also noteworthy here that attempts to model individual components of the human body, often of very complex nature, are also made. An example may be the study reported in paper [12], covering the modelling of the human vertebral column complete with the associated muscular and skeletal system within the scope of research on stability and vibration of the vertebral column.

"Biomechanics" (a term used as a synonym of "biodynamics") "is the science of the physical, biological and mechanical properties or responses of the body, its tissues, organs, parts and systems, either with reference to impressed forces or motion, or in relation to the body's own mechanical activity" [13]. A similar definition has been formulated in study [14]. The authors of the latter state that biomechanics, i.e. mechanics of living systems, is the interdisciplinary science of reasons for and effects of the application of external and internal forces to biological systems (e.g. human body, animal, insect inclusive, or plant), at both the macroscale (when the forces act on the whole organism or on a specific segment of the body) and the microscale (when the action on a single cell or its part is considered). A coincident definition is given in [15]: biodynamics has been defined there as the science of physical, biological, and mechanical (inertial) properties of a human body or its analogue, its tissues, organs, parts, and systems and of reactions thereof to external forces (external biodynamics), inclusive of internal derivative vibration, or to internal forces generated in result of interactions between external forces and body's own mechanical actions (internal biodynamics).

Various types of biodynamic models are possible, including physical, mathematical, and animal models. The models are not expected to function identically in every way as their originals. The model may represent one or more aspects of the original system. The users of the model must know the accuracy of representation of the original system offered by the model and the model applicability range.

Every modelling of body movements and forces acting on the body is challenged by many difficulties. As examples, the following may be mentioned here [13]:

- Complexity in the structure and properties of the body;
- Difficulties in measuring movements and forces in the body;
- Non-linearities in the system;
- Voluntary and involuntary muscular control over body posture;
- Difficulties in obtaining empirical data on the properties of body tissue;
- Incomplete understanding of the modes of movement of the body.

Meanwhile, we know that the important system parameters include:

- Stiffness of intervertebral discs and ligaments;
- Damping in intervertebral discs and ligaments;
- Stiffness and damping in various muscle groups;
- Stiffness and damping in various osteoarticular groups;
- Masses and moments of inertia of individual anatomic structures of the human body.

The searching for a complete engineering model of a body response is unrealistic. On the contrary, the most useful model in every case is likely to be the simplest one that provides a sufficiently accurate prediction of the response of interest.

Complex models reflect complex hypotheses that, for the time being, are unlikely to have been tested and verified. The complexity of a model can only be justified when the mechanisms represented by the model are known. For example, biodynamic models can be used for the following purposes [16]:

- To represent understanding of the nature of body movements;
- To predict the influence of variables affecting the biodynamic response;
- To provide a convenient method of summarising average experimental biodynamic data;
- To predict movements or forces caused by situations too numerous and varied for experimental determination;
- To predict movements or forces caused by situations too hazardous for an experimental determination;
- To provide information necessary for the optimisation of isolation systems (and other systems) coupled to the body;
- To determine standard impedance conditions for the vibration testing of systems used by man.

Another application of models of this type may be the testing of power distribution and energy flow in a man-machine system [17].

It is not fully correct to state that the modelling of dynamic responses of the human body is sufficiently justified by the desire to reduce the harmful impact of mechanical vibration or shocks on human health. The prediction of the forces and movements that may occur in the body constitutes only a small step towards the prediction of the effects of vibration on human health: at each location in the body, the exact relation between force and injury or disease is still unknown, but presumably, it is extremely complex and, to a significant extent, time-dependent. To justify the usability of models for such applications, it is necessary to identify and validate not only a biodynamic model but also a model of the relevant injury mechanisms [13]. At biodynamic modelling, important are the significant differences that occur both between and within subjects ("inter-subject variability" and "intra-subject variability," respectively). The people to whom a model applies may be restricted based on their age, gender, size, fitness, experience, etc. Most relevant models predict only one value for each input, but there is usually a large variation in response between and within real subjects. Therefore, the models are required to reflect the actual distribution of the responses.

Important is also the issue of the data needed for the construction of models. Models may be built without having actual data or without taking the available data into account, but with making use of data defined by guesswork. For example, an assumption may be made (or a suggestion may be put forward) that there is a resonance at a specific frequency for a specific part of the body and, in consequence, a kind of a qualitative or quantitative model of this resonance may be proposed without presenting any evidence to support this assumption. An example of such an approach is the study reported in [18]. Even some well known models have evolved more due to the wish of making the model more sophisticated than to the will of better understanding or obtaining more accurate representation of the effects studied. Some models of this kind are not claimed to represent any specific input-output relationship with defined accuracy or any specific mechanism. However, in so far as they make no specific claim they cannot be easily refuted.

2.1. Types of biomechanical models

As regards the issue of model types, M. J. Griffin proposed in his study [13] to consider three different model forms that do not exclude each other.

2.1.1. Mechanistic[1] biodynamic models

A "mechanistic model" is defined as the one where an assumption has been made that the laws of physics (and chemistry, etc.) will be sufficient to make useful predictions of human response. It is to facilitate the understanding of the body motion. Such models represent, in some way, the mechanisms involved in the biodynamic responses of the human body. In practice, a purely mechanistic model cannot yet be defined because the mechanisms associated with most biodynamic responses are complex and poorly understood.

Many of the published biodynamic models of human responses to vibration have been formed as simple combinations of masses, springs and dampers. Some of these models

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[1] "Mechanistic" means "trying to explain the phenomena and processes that are not mechanical motion with the use of ideas and laws of mechanics." [21]

may provide useful approximate relationships between the independent and dependent variables. However, they have mostly been developed by selecting the form of model without considering how the body moves; the model parameters were merely adjusted so that the input-output relation matches some measured, or estimated, transfer function (e.g. the data describing the transmissibility or impedance of the system) [18]. It is certain that most of these models misrepresent how the body moves internally. Such models provide a convenient form of communication because they present complex responses in the form of printed pages or computer programs. Nevertheless, they have no predictive power and are no more accurate than the values or curves to which they have been fitted; therefore, they cannot be considered mechanistic models. Examples of the mechanistic models having been developed may be found in publications [20] and [17]. It should be stated, however, that any experimental data that might be taken as a basis for models of this kind to be built or validated are not widely available.

A mechanistic model represents current knowledge of a defined mechanism and it will be superseded by a "better" model as knowledge improves. In so far as mechanistic models contribute to the development of knowledge they constitute successive steps necessary for scientific progress.

The models that are to represent mechanisms are definitely satisfying. If a specific mechanism is correctly identified and understood, such models can make it possible to predict a response that has not been measured. Thus, a model with one degree of freedom might be considered a mechanistic one.

A mechanistic model usually represents certain parts of the body; therefore, adequate knowledge of such parts is required for the model to be built. For this purpose, anatomical data and information about mass, stiffness, and damping may be needed. Alternatively, as stiffness and damping are difficult to be obtained directly from a living tissue, data obtained from dynamic tests may suggest suitable values required so that the model could give expected input-output relationships. For this reason, the parameters of such models are derived from both understanding the mechanisms and curve fitting to the measured biodynamic responses. This may lead to simplifications consisting in the use of a model of the human body (with one or several degrees of freedom) without taking the body anatomy into account [22], [23].

The following forms of a mechanistic model are possible [13]:

a) Qualitative description of the way how the body moves. An example may be an expression describing the body response resulting from specific resonances.

b) Mechanical system whose response represents some characteristic features of the system that produces the phenomenon considered the system output. An example may be a model making it possible to predict effects of the characteristic features of the model (e.g. body posture or mass).

c) Human cadaver.

d) Animals (living or dead; whole or parts).

The above description defines the range of applicability of the mechanistic models.

The formation of a mechanistic model requires consideration of what mechanisms are relevant to the input-output relationships of interest. This type of modelling encourages the traditional scientific cycle of model formation, hypothesis testing, model refinement, further testing of hypotheses, and so on.

2.1.2. Quantitative biodynamic models ("input-output" models)

Some models represent input-output relationships without claiming to represent the mechanisms that relate the output to the input: these are quantitative input-output (non-mechanistic) models. Currently, most biodynamic models fall into this category. The quantitative models sum up biodynamic measurements.

A quantitative biodynamic model should predict one or more of the responses of the body to a force or motion. Notwithstanding the apparent complexity, biodynamic models usually are not sustainable mechanical systems: in most cases, they only offer a one-directional response. The excessive simplicity is evident when a mechanical structure is formed to represent the response of a model made in the form of an anthropodynamic dummy. The dummies of this type have been developed for crash test purposes; in consequence, there are few dummies now that are capable to represent human responses to vibration and repeated shocks. Some have concluded that a system with little more than one degree of freedom may provide satisfactory representation of body impedance for seat testing. For such purposes, a quantitative (non-mechanistic) model would be sufficient, because the mechanisms of body movement are of no importance if the impedances at principal points of contact with the seat are adequately represented [24]. For models of this type, a single pair of measurements of the relationship between an input and an output makes it possible to fit a model of interest (i.e., something convenient to the modeller) to the available data, but such a model has no predictive power. The model may indicate what will happen when the inputs are different from those on which it is based (e.g. for other vibration magnitudes or frequencies), but the predictions are not based on data or knowledge of the relevant mechanisms. For example, many linear models have been proposed without evidence of the range of magnitudes or frequencies over which a linear model is appropriate.

The following forms of a quantitative model are possible [13]:

a) Table of numerical values showing a definite response to a definite input. An example may be tables of measured values of vibration transmissibility between the system input and output.

b) Equation representing the numerical values referred to in item (a) above. An example may be a mathematical equation having a specific form and parameters.

c) Idealised mechanical system whose response (or responses) would be similar to the numerical values referred to in item (a) above. An example may be linear or non-linear models of one or more degrees of freedom, continuous models, or models based on the finite element method.

d) Mechanical dummy giving responses similar to the numerical values referred to in item (a) above. An example may be the anthropodynamic dummy used to represent the body impedance at the testing of seats.

The above shows the range of applicability of the quantitative models.

A wider set of measurements, covering a range of conditions, makes it possible to build models having a greater known range of applicability. High variability of data (e.g. strong impacts of subject variability, posture, non-linearity, cross-axis coupling) can suggest models different from those constructed with fewer data. The models may be more sophisticated if they are to enable the observation of effects of all the principal variables or simpler if it is recognised that greater model complexity will not result in better accuracy of the responses of a randomly selected subject.

2.1.3. Effects models

Models of the effects of motion on the body may be quantitative and might be partly mechanistic. They should provide a possibility to predict the effects and be useful in preventing those considered undesirable. An effect of interest to some modellers has been the potential for bodily injury from vibration or shock. However, the limited understanding of the mechanisms involved in such injuries inhibits the development of relevant mechanistic models. The construction of quantitative (non-mechanistic) models is inhibited by the difficulty of measuring relevant inputs, identifying and measuring the outputs (e.g. injury or pain), and shortage of data relating inputs to outputs. Consequently, some researchers feel at present that there is little benefit (and some dangers) in using biodynamic models to predict injury, compared with the application of less pretentious, but simpler, guidance based on vibration severity measures having already been standardised. Notwithstanding the doubts, the development of injury models is a worthy objective presenting a multidisciplinary challenge that will require a rigorous scientific approach to avoid a variety of pitfalls. The effects models make it possible to predict the impact of motion on human's health, comfort level, or efficiency.

The following forms of an effects model are possible [13]:

a) Numerical values showing the probability that a specific injury (or disease) of a specific degree would take place at a specific input.

b) Equation representing the numerical values referred to in item (a) above. An example may be the mathematical models used at crash tests.

c) Idealised mechanical system with a calculable response that would be similar to the data referred to in item (a) above. An example may be the dummies used at crash tests.

The above description defines the range of applicability of the effects models.

Effects models need evidence that the effect is caused by motion or shock, knowledge of the type of motion causing the effect (i.e. a means of quantifying the cause), knowledge of the effect (i.e. a means of quantifying the effect) and knowledge of the relationship between cause and effect. Where a specific effect may also be caused or moderated by other factors, the representation of their influence in the model may also be needed.

A human response (i.e. effect) of interest is unlikely to be well predicted by a biodynamic model if the influence of relevant anatomical parts and factors influencing the body response of interest are not included in the model. For example, forces in the spine are thought to be highly dependent on body posture, so it does not seem likely that a model will provide a good prediction of injury if the influence of posture is neglected. Similarly, if damage to a particular tissue is of prime interest, most likely some characteristics of this tissue should be included.

In recapitulation, we may state that both the quantitative ("input-output") models and effects models will gradually become closer to the mechanistic ones. However, the mechanistic models are those that pave the way for the development of knowledge and the construction of models of the other types will follow and depend on this stage.

2.1.4. Specific models

Animals, cadavers and mechanical systems can be used to represent humans (they may be mechanistic, quantitative, or effects models discussed above). A separate group may be formed from specific models [6]; some examples have been described below.

Specific models. Animal models

For an animal model (living or dead) to be used, the extent of any difference from living humans must be known.

For some types of study, it may be possible to determine by experiment that similar (or predictably different) results are obtained for humans (or human tissue), and animals (or animal tissue). Useful information on human responses may then be estimated from the responses of animals. Aside from moral arguments over the use of animals, it might be argued that the gathering of information about animal responses and the understanding of such responses is a valid scientific pursuit irrespective of the applicability of the data obtained. Animal models may therefore be mechanistic, quantitative or effects models of human responses.

Specific models. Anthropodynamic dummies

Anthropodynamic dummies may be mechanistic models, but the information required for a mechanical dummy representing some aspects of human response should primarily include the relevant input-output relationships for a model of this type. It is not normally necessary for the internal movements of an anthropodynamic dummy to be governed by mechanisms identical to those specific for the human body. At present, anthropodynamic dummies are chiefly used for crash testing [25] and seat testing. The dummies of both types should be capable of calibration to a defined accuracy and they should make it possible to obtain measurement results with a known degree of repeatability. They should represent the principal body responses of interest for the whole range of applications in which they are to be used. A dummy required to indicate the hazards of a specific motion should provide (directly or indirectly from its movement) one or more signals that can reasonably be assumed to reflect the hazard. Within the bounds of understanding, it should be expected that design changes that would result in changes in the signals produced by the dummy would also affect the estimates of the risk of injury. This requires knowledge of the parameters that would cause the injury.

Seat test dummies should simulate the dynamic interaction between the seat and the human body so that the motion measured on the seat with a human subject seated on it is similar to (or can be calculated from) that measured with a dummy [25]. This may require the dummy to have impedance similar to that of the human body, appropriate non-linearity, and suitable coupling to the parts of the seat with which it is in contact. This implies an assumption that human mechanical impedance, non-linearity, and body-seat coupling have already been known.

A biodynamic (biomechanical) model is, at best, a representation of only a few aspects of the human body, while it should represent (we want it to represent, we are striving for it to represent) the biological functions as well. It is meaningless to refer to a model as being a "validated" one without stating how the model can be used. It is necessary to identify what the model represents and how the model predictions compare with observed human responses.

Various biodynamic models are possible, with different justifications, different applications and different requirements for "validation." Many current models are quantitative ("input-output") ones and offer no more information than the data on which they have been based: they may even contain less information than the original data and may give misleading representations of the relevant mechanisms.

3. Conclusions

The issues related to biomechanical modelling have been discussed in this paper. Various biomechanical modelling methods used to study the phenomena taking place in transport facilities has been reviewed.

A biomechanical model may represent only a few aspects of the human body. Model validation should include comparisons between the predictions of the model and independent observations of the predicted responses. For "quantitative models," the specified error should be compared with measurements over the full range of application of the model. It would be unwise to accept an "effects model" unless it is known that vibration or shock is a proven cause of the specified effect, there is a positive correlation and acceptably small error between predictions of the model and the observed effect throughout the range of application of the model, and other variables having a large influence on the effect are taken into consideration. Quality checklists are given for "mechanistic models," "quantitative models," and "effects models." At scientific methods, value judgements (e.g. "validated" or "not validated") are unacceptable. A claim that a model (or method) is validated may be ill considered. It is more helpful to quote the applicability limits and the errors of a quantitative model (or method) than to claim that the model (or method) is "validated."

It should be stressed that, in terms of practical importance, biomechanical systems are characterised by the following specific features as against mechanical systems:

1) Complex or very complex structures must be modelled, in result of which greater simplifications must be made than it is in the case of mechanical systems. In consequence, the results obtained are burdened with a greater degree of uncertainty.

2) Very wide scatter of data such as geometrical or mass quantities or material properties is observed.

Nevertheless, biodynamic models may be used to predict the risk of injuries or diseases. They may also be used for the optimisation of structures in order to minimise hazards (e.g. harmful vibration impact). However, such models cannot be promulgated and used without the knowledge of their accuracy or suitability for specific cases.

The validation of the models described here may be confirmed by answering the following questions:

a) For a mechanistic model: Has the specific mechanism been clearly defined?

b) For a quantitative model: Have the input-output relationships been properly defined?

c) For an effects model: Has the type of the effect predicted been clearly defined? Has the intensity of this effect been defined? Has the probability of this effect taking place been defined?

Further work in this field should be directed towards the modification and development of models, where the following aspects should be taken into account:
- Stiffness and damping coefficients of body parts;
- Curvatures of parts of the skeletal system, especially of the vertebral column;
- Non-linearities of body parts;
- Energy (power) absorption by body parts.

The permanent development of informatics, control theory, and cybernetics may be expected to enable the addressing of the above issues to an extent ensuring that the aspects related to the functioning of the human body would be represented, in order to "depart" from the classic mass-spring-damper mechanical system. This will require interdisciplinary activities.

At the end of these deliberations on biomechanical modelling, it is worth emphasising that biodynamic models are needed for any methodical analyses of the man-vehicle relationships, e.g. the relationship between exposure to vibration and comfort. However, the scope of application of such models should be limited to that for which they have been validated. In turn, numerical computer models of dummies will be useful to support the development of systems aimed at a reduction of vibration impact in the man-vehicle system [27], [28].

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