HOW TO DETERMINE THE EFFECT OF WORKING CONDITIONS ON THE HUMAN BODY

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Musculoskeletal Simulation, Ergonomics, Work Place Design

ABSTRACT
Work places and conditions strains the human body, both psychologically and biomechanically. In order to analyse working conditions and in the following to improve them, detailed knowledge about the effect of the different stressors on the body is needed. This manuscript discusses methods on how to evaluate biomechanical and mental loading and its effect on the musculoskeletal system. A possible workflow for the analysis is presented.

1. INTRODUCTION

Today's working places and conditions (WPC) have come a long way and have undergone drastic changes. The beginning of industrialisation has dramatically changed living and working. During the last century, work conditions improved in many areas with an increased safety and rectified ergonomic solution for employees. Despite the general trend, onward tremendous efforts are necessary to improve quality of work places. This effects people at all levels of income and is therefore extremely diverse. Particularly in low paid manufacturing jobs small changes could improve the quality of life for many. Specifically their WPC needs to be considered as their impact on society is mostly effected. Especially most European societies are on the onset or in fact in the middle of a transition. In recent decades technology has completely changed the way we communicate and how goods are traded.

Digital and intelligent networks give way to a new way of thinking in industry by linking production with information and communication technology. The aims are self-optimising processes involving all stages of the life cycle of products. The optimization is shifting more and more to involve human factors. This process involves flexible working hour models, right up to outsourcing work places to home offices.

Next to a rapidly changing industry, also the demography of many European societies is changing. Life expectancy is increasing and birth rates are low in many countries. The consequences are increasing working lifetimes in order to compensate the mismatch in the society.

Speaking of WPC these aspects as well as others have to be taken in to account. On one hand we have in many places an altered stressor with a larger emphasis on cognitive components, multi-tasking and permanent incoming information. On the other hand we have to face the fact of older population, an often lowered stress resistance against both, mental and physical loading.

Recent data provides reasons for work absence in Germany revealed again the importance of musculoskeletal and psychological issues. Which are the two most dominant factors for work

inabilities. Musculoskeletal disorder accounts for around 23% of all work absences. Mental health problems are increasing over the last few years and are in 2016 responsible for around 17% of work absences. [1]. Interestingly, almost all economic sectors report an increase in stress level for recent years. Statistics from 2012 show an increase of 45% of stress level for manufacturing industry and a quantitative over-stress of 17% [2], indicating an growing need for interventions.
Next to the personal burden, health problems result also in high financial expenses for companies. In 2009, 129 Billion € have been carried by the companies in Germany due to health problems of their employees [3].
Obviously, quality of life of the individual as well as economic cost set the demand for improved working conditions in our modern societies.
Therefore, the aim of this article is to describe some of the main stressors on workers and to show ways how to analyse the individual loading of workers and derive possibilities for interventions.

2. DETERMINATION OF PERSONAL STRAIN

On a macro-level we can elaborate the response of a human to a particular context as an interaction of three components: Environment – which is acting on the individual, physical human capacities (PHC) often referred to as traditional ergonomics and cognitive human capacities (CHP) often referred to as human factors [4].

Table **1** shows some of the stressors and corresponding responses of humans.
We want to focus on psychological and biomechanical (PsyBio) interaction. Biomechanical loading – quite straightforward - results in altered musculoskeletal loading and altered postures. This results in altered tissue loading and may lead to a general overload and degeneration. One example for inadequate ergonomics is prolonged overhead arm postures of construction workers. This body position results in increased activity of rotator cuff muscles and concentrated loading of glenoid components. On the long run this may lead to tendon ruptures in the shoulder muscles and shoulder joint degeneration. Mental loading can be due to different stressors. At the workplace psychosocial stressors like low job satisfaction has been the subject of intense research [5]. In many studies these stressors were found be associated with the development of musculoskeletal disorders [6] even as a causal impact [7]. A slightly more differentiated consideration about possible psychological stressors may speak of cognitive, emotional, social and physiological stressors [8]. The first response can be mental strain, which might initiate a biophysiological reaction such as altered electrodermal activity (EDA) or heart rate variability (HRV) [9–11]. Next to this, mental stress has also been shown to increase muscle activity in neck and shoulder muscles [12–14]. This establishes a direct link between biomechanical and biophysiological responses. Changed muscle activation and therefore muscle loading alters the musculoskeletal loading and might also alter posture. Therefore, mental stress has also the potential of directly influencing tissue loading and tissue remodelling/degeneration processes. Other possible links are initiated through biochemical body responses [15] or increased physiological susceptibility [16,17] that might initiate inflammatory processes or affect circulatory and respiratory responses.
There are several accelerating and decelerating factors, which play a role in the separated and combined Psybio responses. The person’s musculoskeletal condition and resistance influence the progression from overuse/misuse musculoskeletal loading to functional and tissue degeneration. Dominant factors are age, training status and history of musculoskeletal disorders. The latter two factors are well established to be highly influenced by age. The individual reaction to stress is altered by factors like age, gender, genetics, social factors, individual coping strategies like stress appraisal and personality [18,19]. In the context of combined biomechanical and psychological investigations, the individual’s personality is one of the most pronounced parameters. A large variability of biosignals representing the biophysiological answer to stress can be found. In consequence for example muscular stress reaction in the shoulder region has been shown to be dependent on personality [20]. Nevertheless, only few studies have investigated the direct influence of stress on

musculoskeletal loading. Next to muscular activation, lumbar spine loading in relation to subject's personality for lifting has been analysed [21] as well as in relation to psychosocial stress [5].

Table 1: Biomechanical and psychological loading and respone cascade.

	Biomechanics	**Psychology**
Loading	Static /dynamic passive tasks static /dynamic active tasks Vibrations …	Cognitive stressors Emotional stressors …
1st Response	Altered musculoskeletal loading Altered posture	Mental strain
2nd Response	Altered tissue loading	Biophysiological response: Heart rate variability, skin temperature, muscle activation,…
3rd Response	Tissue degeneration / remodeling	Mental problems

A first step to improve WPC is to gain knowledge of the status quo. For this, detailed analyses of the environment and the measurable responses of the body are needed. Whereas experimental setups allow sophisticated laboratory methods, in field analysis are much more demanding but also favourable. Video based motion capture methods are still considered as gold standard for the study of human body motion. However, the out-of-lab usage is often not possible. Therefore, alternative approaches are required. In recent years, methods have been developed, which enable the analyses of motion through inertial measurement units (IMU) [22]. Even so, accuracy is still an issue, IMU's gives a method to monitor daily routines. Physical forces acting on the body are usually difficult to measure. Several workplace simulators have been proposed, but again this is mainly limited to a laboratory setup. The quantification of psychological strain has been traditionally the field of questionnaires. However, a more objective way to study the influence of stressor on the human body is given by the biophysiological response. These signals can be collected in both environments, laboratory as well as in field. Usually, the signals are quite sensitive to changes in test conditions, prone to measurement errors and should be recorded and analysed very carefully. Own laboratory studies have shown, that HRV has advantages for real life applications.

Table 2: Methods for experimental determination of human body loading.

	Biomechanical		Psychological
	Kinematics	*Kinetics*	
In laboratory	Video based motion capture, Inertial measurement units	Force platforms Workplace simulators	HRV, EDA, skin temperature, questionnaires, pupil diameter (PD), eye gaze and blinking
		Muscle Activity (EMG)	
In field	Inertial measurement units, Wearables, Video based systems		HRV, EDA, skin temperature, questionaires

3. MUSCULOSKELETAL LOADING

Measuring human body kinematics and interface forces sheds some light on the musculoskeletal loading situation. In many cases, traditional ergonomics stop here and derive interventions based on this data. In the last decade, musculoskeletal simulation has gained a lot of attention for analysis of internal biomechanics of bodies. Numerous groups have developed sophisticated modelling systems as well as human body models. These models are for example extensively used in orthopaedic research (e.g. [23–25]. Most prominently, OpenSim (http://opensim.stanford.edu/) and the commercial software package AnyBody Modeling System (http://www.anybodytech.com). In general, the underlying principles for musculoskeletal analysis are inverse or forward dynamics. In forward dynamics, sets of muscle forces have to be given (or optimised) for a desired motion. Due to computational expenses, this restricts the analysis often to human body models with a low level of detail. In contrast, inverse dynamic analyses compute the needed muscle forces for a given motion (Figure ***1***). Hence, reliable motion data is required for the analyses. Human body models for inverse dynamics can reach a high level of detail (e.g. [26]. For example, the current full body models of the AnyBody Managed Repository feature above 1000 individually activated muscles. Computing the muscle and joint forces requires additional knowledge on the way muscle are recruited. One way to deal with the mechanical overdetermined system with more muscle forces then free degrees of freedom in the human body is to use optimisation methods. Several methods have been suggested. Most commonly squared or cubic optimisation of muscle forces are used. The rationale behind this a mechanical optimised way e.g. in order to prevent fatigue in which the central nervous system is recruiting the muscles [27].

As mentioned above, input to inverse dynamics contains data on kinematics and force boundary conditions. With this information, muscle and joint forces are computed. The knowledge of internal body loading can further be used to compare forces generated by various complex situations. This enables us to given tissue/construct limits for certain activities or to analyse the musculoskeletal loading as well in status quo and moreover the effect of interventions.

Utilizing inverse dynamics sets the need for motion data; however, optimisation methods enables the analyses of optimal postures and motions. In order to achieve reasonable results, the input to musculoskeletal models are altered and optimised to get a desired motion and loading pattern.

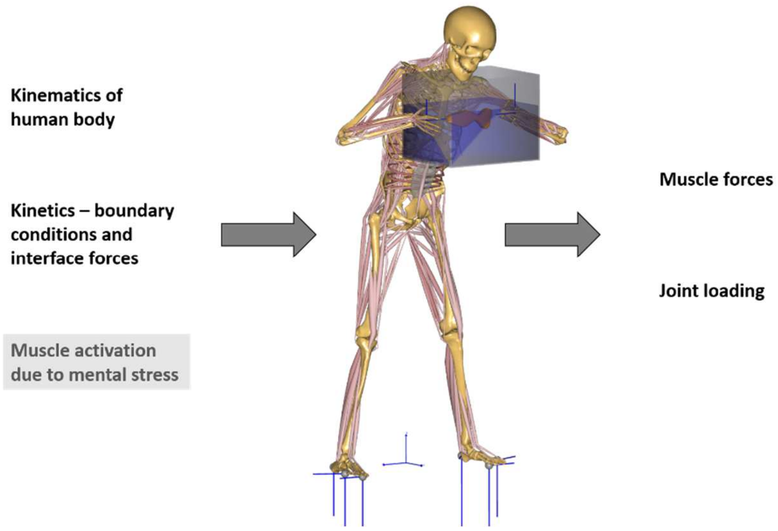

Figure 1: Musculoskeletal simulation input and output

As discussed, mental stress influences muscle activation and biochemical processes. On the level of musculoskeletal simulation the former is of primary interest.

The simulation of mental stress and the influence on the musculoskeletal system can be accomplished either by simulating the neural stimuli in the brain and derive the effects on the nerve system effecting the muscle recruitment. Or another way is to approach the problem from the side of the muscle recruitment itself. Therefor changes in muscle recruitment of the main muscles are measured using surface EMG. This is done for normal baseline circumstances and in a following step, the identical experiment is carried out under the influence of the various stressor types. The changes in muscle activity can afterwards be used for musculoskeletal simulation. At first, the baseline measurement is simulated using exactly the same boundary conditions for kinematics and kinetics as in the experiment. Due to the nature of inverse dynamics the result includes not just forces and moments in the human body, but also the muscle activities necessary to achieve the movements. In a subsequent simulation run, the procedure differs from real life. Instead of applying the stressor to the model, the changes in muscle recruitment are applied. Hence, the muscle activities are altered and bounded according the previously measured changes. As mentioned above the over determined system must be solved to maintain a kinetic equilibrium to maintain the human motion. This results in an overall different muscle recruitment effecting loads as well as the activity of particular muscles. In a similar manner, changes in kinematics could be additionally included. Depending on the application, individualisation of the models can be of high importance.

4. EXAMPLE

Whereas there is plenty of work analysing biomechanical loading at work places (see e.g. [28–30] little is reported in literature about the influence of stress on musculoskeletal loading. This example displays the effect of cognitive stress on spinal disc loading in lumbar and cervical spine. Measured quantities are: Kinematics of the human body through video based motion capture, Muscle activation on the back with 12 EMG sensors (*Figure **2***), biophysiological response with EDA, HRV and skin temperature. The test protocol investigates the isolated effect of the stressor on the test subjects in a static seating position. Therefore, a cognitive stress test is applied to the test subject and responses are measured. A musculoskeletal simulation of the test subject is utilized, in which the muscle activation due to the stressor is included. Comparing the non-stressed to the stressed situation reveals the influence of stress on spinal loading.

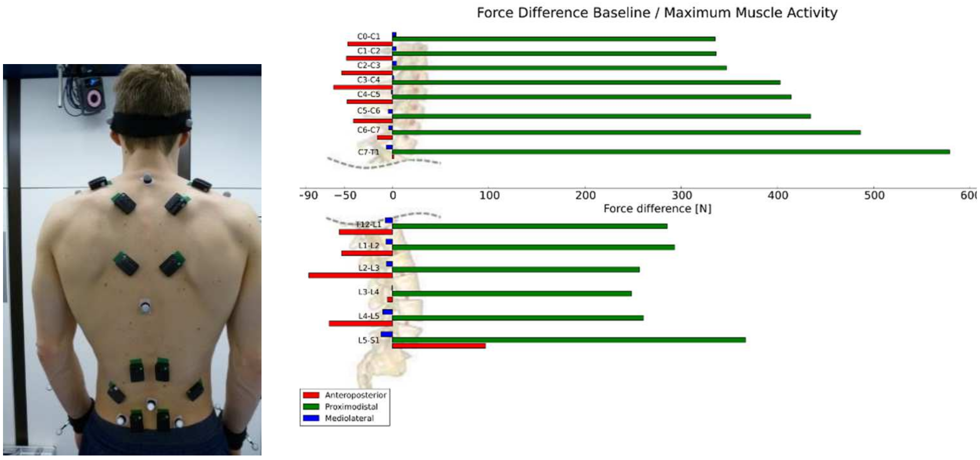

Figure 2: left) Example for measurement of muscle activity through surface Electromyography. right) Computed cervical and lumbar spinal disc loadings purely caused by mental stress.

Figure 2 shows results for a spinal disc loading due to stress. The forces shown are generated exclusively due to mental stress in absence of any dynamic motion. Peak forces in proximodistal direction are incereased by up to 580N and for shear components up to 100N. This large force increases indicate a dominant role of mental strain on musculoskeletal loading.

5. CONCLUSION

Work places and conditions should be analysed carefully according to their mechanical and mental strain. Especially the combined psychological and biomechanical loading has to be considered. A range of experimental as well as numerical methods is available that gives insight in internal body loading. This data may help to elaborate on the improvement of working conditions by making the impact of the environment quantifiable and identifying critical spots in the human body, which are subject to loadings leading potentially to musculoskeletal disorders. Furthermore, automated recognition of stressful situations are necessary in order to apply at the current event strategies, which prevent harmful processes.

6. LITERATURE

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