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Evaluation of Physical Workload Using Simulation Versus Motion Capturing Data for Biomechanical Models

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Abstract. Throughout Europe, work-related musculoskeletal disorders (WRMSD) are still a major problem as they are most often associated with lower back pain or other physical complaints. In order to improve workplace safety and avoid WRMSD, it is therefore essential to analyse physical risk factors. Digital Human Models (DHM) can help to estimate ergonomic risks in working conditions. Traffic light schemes are commonly used to quantify the physical strain, while biomechanical loads are often neglected. The limitation of biomechanical models is, however, that they require motion data for their predictions. These data are time-consuming to capture and require camera-based or sensor-based methods. For this reason, a coupling between the "AnyBody Modeling System" and the "Editor for manual work activities" (ema) was developed to expand ergonomic evaluation with biomechanical parameters, without using motion capturing data. The findings indicate that the computer-generated motions of the interface rarely match real motions, therefore, the results of biomechanical loads have to be interpreted with caution. However, the coupling between AnyBody and ema allows to estimate the physical stress of specific activities. For a better understanding of physical workload another research approach is proposed taking kinematic and kinetic real-time data of workers into account to improve physical risk assessment in future.

Keywords. Ergonomics, Biomechanics, DHM, WRMSD, Inverse Dynamic, Risk Assessment

1. Introduction

Although the topic of work-related musculoskeletal disorders (WRMSD) has been frequently discussed in the last decades it is still up to date. Since the consequences of WRMSD are manifold as they result in substantially economic costs and impair the quality of life of the affected employees. About 60% of the workers in the EU-27 suffering from musculoskeletal complains, while shoulder, neck, upper limbs and lower back are often affected [1, 2]. Many of these diseases are linked to overexertion caused by manual material handling (MMH), which include unaided lifting, lowering, holding, carrying as well as pushing and pulling tasks. They result in high physical loads and can be indicators of an ergonomic risk. In this context, biomechanical loads can provide helpful information to estimate physical stress on the musculoskeletal system in working conditions. Compression forces of the lumbar spine, for example, are influencing factors

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considering lumbar diseases in occupational tasks [3-5]. In addition, high reaction forces in the shoulder girdle, caused by external loads, are also considered as risk factors [6-7] and may lead to permanent restrictions. Therefore, human-centered design of workplaces is essential to avoid WRMSD and maintain physical health of employees. In accordance with the Framework Directive [8], the employer is obliged by law to perform a risk assessment for reasonable working conditions.

Today a variety of tools, ranging from checklists to complex virtual simulations and real-time measurements, are available to estimate physical risk factors and improve work safety. The advantage of paper based risk assessment methods, e.g. Key Indicator Method (KIM) or Ergonomic Assessment Work-Sheet (EAWS), is that they do not require much preparation time. The disadvantage, however, is that biomechanical loads cannot be estimated with these approaches. The limitation of biomechanical models instead is that they require comprehensive data to run virtual simulations. The data acquisition e.g. with motion capturing is time consuming and less practical but the results provide more detailed information. With this in mind, an interface has been developed to exchange computer generated motion data of the Editor for manual work (ema) to run biomechanical analyses in the AnyBody modeling system without using motion capturing data. The main goal of the research project ema2AnyBody was to enrich ergonomic analysis with biomechanical parameters, on the one hand, and facilitating biomechanical analysis for physical risk assessment, on the other.

2. Method

A major challenge in exchanging data between Digital Human Models (DHM) are non-standardized protocols, concerning skeleton configurations and data file formats. This problem was frequently addressed in the literature [9-12]. Until today, for several reasons, no general recommendation is at hand. In the research project, the Biovision Hierarchical (BVH) file format was therefore used to exchange skeleton configurations, movements and forces between the ema and AnyBody model. These information are necessary to determine biomechanical joint load. To overcome the challenge of scaling a standardized DHM in ema and AnyBody was used, representing the 50th percentile male (body height) in Germany [13]. Another key issue is that computer generated movements, especially when forces are applied, do not change their movement strategies in an appropriate way. This can lead to problems during invers dynamic analysis as the movements become dynamically inconsistent. To prevent these problems the *over-determinate kinematics* algorithm [14] was used to optimize the movements before running invers dynamic calculations. More detailed information about the AnyBody model can be found here [15]. Furthermore, the optimization should additional contribute to a more realistic movement strategy. To ensure that the interface between ema and AnyBody provide reasonable data an investigation was performed taking kinematic data of subjects during MMH tasks into account. Kinematic data were used to run the same body model of the interface.

Nine healthy male subjects, stature 1.75 (0.04) m, 76 (9.1) kg, age 29 (5), participate in the study. Several MMH task had to be performed by each subject include lifting and lowering boxes as well as assembly activities with a drilling machine (Figure 1). Kinematic data were recorded using an inertial sensor based motion capturing suit (Perception Neuron). The weight of the boxes (5 kg, 10 kg, 15 kg) as well as the distance to the lifting object (0.4 m, 0.7 m) and lifting height (0.8 m, 1.1 m) was randomly assigned. During the assembly activities the subjects had to apply a force of 50 and 100 Newton with the drilling machine in three different postures (below = b, neutral = n and above = a). To measure the forces the drilling machine was equipped with a one-component force sensor (ALMEMO®). For visualization of the force applied to the sensor, a tablet was installed at the working station. A Visual Analog Scale (VAS) was used to measure the perceived stress of the subjects on scale between 0 and 100. The study was conducted in 2019 under the supervision of the author and the approval of an ethics committee (No. 16.08.2018). A supervision was required to give the same movement instructions to all subjects. Furthermore, the IMU sensors of the motion capturing suit had to be attached on the same anatomical landmarks to reduce the measurement error.

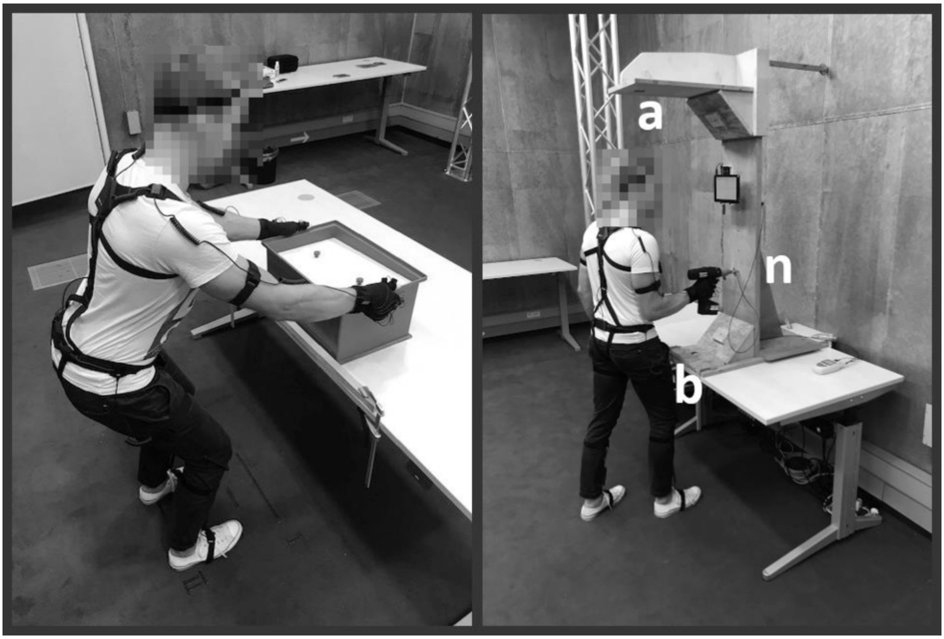

Figure 1. MMH task and assembly activity with a drilling machine in neutral posture.

The kinematic analysis during MMH tasks refer to the time when the boxes were lifted, and while assembly activities to that time period when force was applied to sensor. In the lifting process of MMH tasks subjects were not allow to change their standing position, while during the assembly actives, they could choose a preferred position. Data analyses and statistics were performed with Matlab (Mathworks, Natick, USA), SPSS (IBM Corp., Armonk, NY, USA), ema (imk automotive GmbH, Chemnitz, Germany) and AnyBody (AnyBody Technology, Aalborg, DK).

3. Results

Figure 2 shows angular trajectories of the elbow, shoulder and thorax in MMH task, where the subjects lifted a box of 5 kg with a distance of 0.4 m and lifting height of 0.8 m compared to the computer-generated results of the ema and the interface. Figure 3 reveals angular trajectories of subjects during assembly activity with a contact pressure of 50 N in body posture b. All kinematic results were time normalized. Figure 4 shows some results of the perceived stress of the subjects during lifting and assembly activities. Table 1 presents the maximum joint reaction forces calculated by the interface at the beginning of the lifting process. The shoulder moment (reported in Nm) and the compression force of the L4/L5 joint in N are listed. Table 2 is showing the mean joint reaction forces of the same joints during the assembly activities, calculated by the interface. Mean values were taken while reaction force of the drilling machine was applied. The stress of the shoulder joint and the compression forces of the lower back was of particular interest since they are often associated with WRMSD.

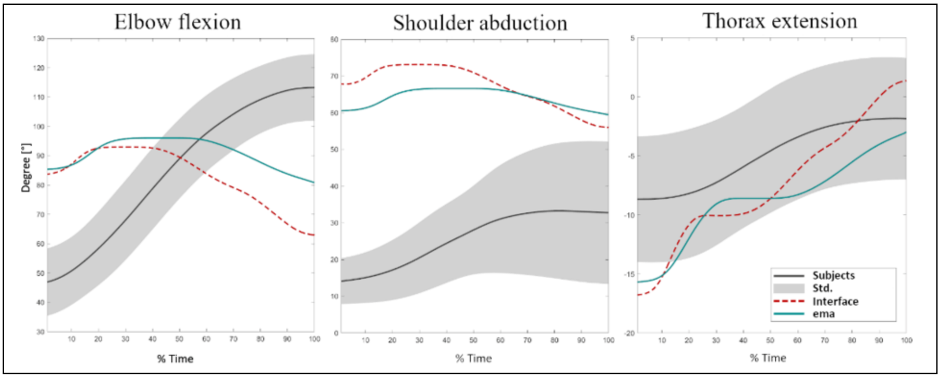

Figure 2. Angle trajectories of movement analyses in lifting condition 80_40_05.

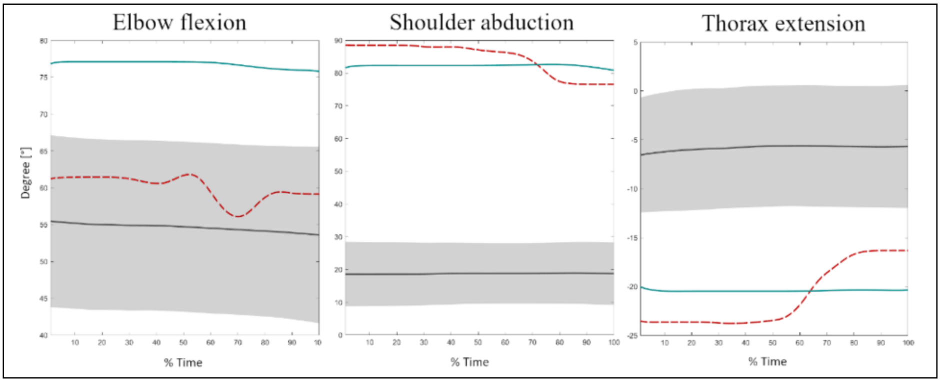

Figure 3. Angle trajectories of movement analyses during assembly activity b_50.

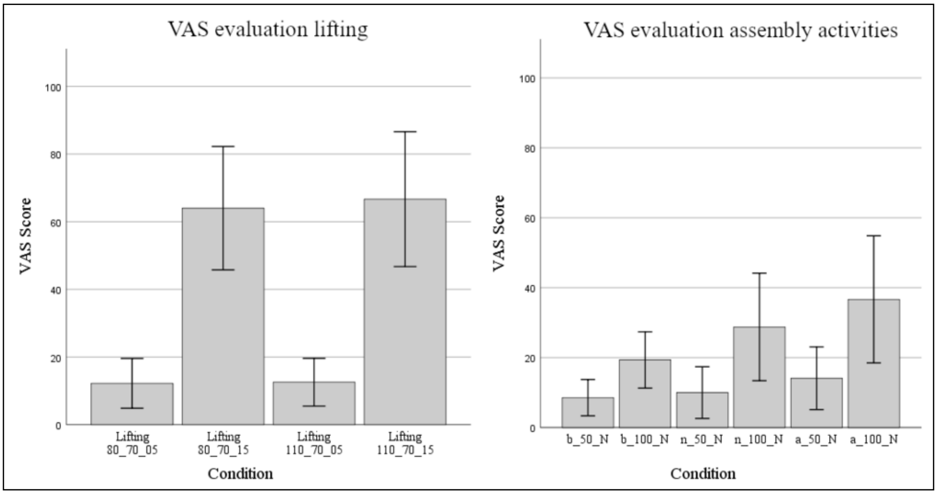

Figure 4. VAS evaluation of subjects.

Table 1. Maximum joint reaction forces of simulated lifting tasks with the interface.

Condition	Compression force L4/L5 [N]	Shoulder moment [Nm]
Lifting_80_70_05	2522	21.5
Lifting_80_70_15	4043	49.3
Lifting_110_70_05	1854	26.7
Lifting_110_70_15	3810	56.2

Table 2. Mean joint reaction forces of simulated assembly activities with the interface.

Condition	Compression force L4/L5 [N]	Shoulder moment [Nm]
b_50_N	525	11.8
n_50_N	911	19.8
a_50_N	1030	25.6
b_100_N	1311	36.5
n_100_N	1435	24.3
a_100_N	1644	41.9

4. Discussion and further steps

For the time being, the results show that an automated data exchange between an ergonomic and biomechanical DHM is possible. In this case, joint loads can be used to enrich ergonomic analysis with biomechanical parameters to provide a more detailed evaluation of workload. On the downside, however, the results indicate that computer-generated movements often differ significantly compared to the movements of the subjects. In some cases, the angle trajectories presented in figure 2 show even opposite directions (e.g. elbow flexion and shoulder abduction in lifting condition 80_40_05). These abnormalities could also be observed in other lifting conditions with short lifting distances. In contrast, the thorax extension show good agreement in all lifting conditions. As a first conclusion it can be summarized that the movement optimization of the interface do not necessarily provide more physiological movements, but is required to run invers dynamic simulations with the computer-generated motion data of ema. Nevertheless, from a descriptive point of view the interface seems to provide in some cases angle trajectories that are closer to those of the subjects (e.g. elbow flexion during assembly activity b_50). However, these cases appear to be incidental, rather than a systematic improvement. It should be mentioned that the main goal of the research project was not the creation of computer-generated movement patterns that are close to human ones, but to establish a data exchange between the ema and the AnyBody modeling system. The perceived stress of the subjects show good agreement in almost all conditions compared to the joint reaction forces of the interface. However, it is noticeable that the joint compression force at L4/L5 during the assembly activity b_50_N is remarkably low, which may indicate limitations of the interface handling several restrictions at the same time. In this case, the reaction force of the drilling machine as well as dynamic inconsistencies that had to be solved may have led to the result. Particular care must be taken in the interpretation of shoulder moments. As already mentioned the shoulder and elbow joint showing substantial deviations between subjects and the interface, which hinders the interpretation of biomechanical loads. Also the intraindividual difference between subjects showing large deviations and complicate the evaluation. The standard deviation can be explained by individual movement strategies of the subjects and inaccuracies of the measurement system. For this reason, the significance of shoulder moment is limited. The huge variance between experimental and simulated joint angels is attributed to the fact that the artificial movement of ema is not affected by the load to be lifted. Thus, the shoulder abduction or elbow flexion undergoes only slight changes in almost all lifting conditions. Furthermore, there were greater differences in the anthropometry between both DHM concerning body segment lengths, as well as joint centers. The issues of posture prediction and coupling of DHM with biomechanical models have already been reported in literature [16, 17]. An approach to address this problem is a similar kinematic skeleton configuration to reduce the errors in the optimization process. This will help to better adapt the kinematics of both models and overcome scaling problems. For the dynamic interaction with the working environment, it is also possible to consider CAD models during the simulation with AnyBody [17].

Nevertheless, the results of compression forces of the lower spine in lifting conditions are more reliable, due to the minor deviation concerning the angular trajectories of the thorax. Accordingly, this biomechanical parameter can be considered as a reference in an ergonomic analysis. Several limitations have to be mentioned: Based on the small sample size, only potential benefits and no general statements can be highlighted. Furthermore, the IMU motion capturing suit, used in this study, does not necessarily provide accurate data, since the sensors can easily be affected by many environmental influences. Finally, the body model was not adjusted to the individual segment proportions of the subjects. Future research should take movement strategies in terms of ergonomics and plausibility into account when data are exchanged with biomechanical models. Since reliable biomechanical simulations can only be guaranteed if the movements correspond to physiological ones.

Due to several limitations mentioned above, biomechanical simulations with computer-generated movement data seems to be difficult at present. Therefore, a new research project was assigned to investigate the risk assessment of workers with a biomechanical model and real-time kinematic data. The aim of the project "Body Information on an Intelligent Chip" (BIONIC) is to develop smart working clothes with integrated IMU sensors to record kinematic data of workers during occupational tasks.

In addition, ground reaction forces are to be measured for a better estimation of physical workload. Based on the data collected, ergonomic risks factors should be identified to detect potentially hazardous body postures during work and to prevent WRMSD. The system is being developed for the ageing workforce but can also be used by others. Individual parameters are taken into account to achieve more accurate ergonomic risks. A challenge in the project will be to develop a system, which generates reliable data over a long period e.g. a working shift or at least several hours, to run biomechanical models. In contrast to the research approach presented in this paper, the focus is on precise movement data and a reduced biomechanical model complexity, which allows calculations in real-time. To evaluate the results of the Body Sensor Network (BSN), a further investigation is planned taking the accuracy of the body model into account, since IMU sensors a highly affected by environmental influences.

However, IMU systems with integrated ergonomic and biomechanical models seem to be of growing interest in occupational safety and health lately, as they offer potential new opportunities to facilitate risk assessment. One concern, though, is that the quality of automated ergonomic systems cannot replace the evaluation of an ergonomist and therefore potential risk factors may be overseen.

Acknowledgement

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