Applied Ergonomics 67 (2018) 225–236

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Multi-directional one-handed strength assessments using AnyBody Modeling Systems

Divyaksh Subhash Chander*, Maria Pia Cavatorta

Department of Mechanical and Aerospace Engineering, Politecnico di Torino, 10129 Torino, Italy

ARTICLE INFO

Article history:
Received 22 March 2017
Received in revised form
27 September 2017
Accepted 29 September 2017

Keywords:
Musculoskeletal modeling
Workplace optimization
Standing exertion

ABSTRACT

Digital human modeling tools support proactive ergonomics in optimizing work tasks and workplace layouts. Empirical-statistical model based tools are often used to estimate the force exertion capability of the operators. This work is intended to serve as an initial probing into the usability of a musculoskeletal model based software, AnyBody Modeling Systems (AMS), in evaluating the force exertion capability at different points in the workspace and for various exertion directions. As a first step, it focuses on the modeling approach and the accuracy of one-handed isometric strength estimates of AMS. An existing literature database was used to compare the predicted strength at 8 hand locations and in 26 exertion directions, while simulating the empirical postures. The results show a correlation coefficient of 0.7 between the simulated and the experimental strength. AMS emphasizes the biomechanical advantages in strength due to the alignment of force exertion direction with the shoulder. Additionally, some discrepancies have been identified and discussed.

1. Introduction

Proactive ergonomics targets the prevention of work-related musculoskeletal disorders (WMSDs) through early detection and reduction of risk factors at work, such as awkward postures and excessive force exertion. Nowadays, Digital Human Modeling (DHM) tools support proactive ergonomics through virtual simulations of work tasks and workplace during the design phase (Longo and Monteil, 2011; Spada et al., 2017; Summerskill et al., 2016; Van Houcke et al., 2017). These tools integrate several analyses such as reachability, visibility, clearance and ergonomic risk assessment, amongst others to evaluate the various workplace alternatives. The aim of these analyses is to optimize the workplace and mitigate the risks of WMSDs, such as those due to awkward postures and excessive force exertion. To this last aim, the knowledge of population strength capabilities is crucial to lowering the risk due to overexertion (Lin et al., 2013), which is also exemplified by the ongoing research in this field (Ekşioğlu, 2016; Plewa et al., 2016; Thompson et al., 2015). Equally, it is critical that the DHM tools are able to model correctly the force exertion capabilities in different workplace layouts, i.e., accounting for changes in work location and exertion directions, to suitably optimize the workplace layout in proactive ergonomics (La Delfa and Potvin, 2017).

There could be two approaches to compare the acceptability of alternative workplace layouts in DHM tools: empirical-statistical modeling and musculoskeletal modeling. The prior consists of well-known software programs like 3DSSPP and Jack and makes use of a static strength model (Chaffin et al., 2006) to evaluate the reactive body joint moments due to the work task requests. These joint moments are compared with empirical population strength databases to estimate the population percentile capable of performing the task. The percentile capable is widely used to compare the work task demands in alternative layouts (Bertoloni et al., 2012; Tripathi et al., 2015; Zhang et al., 2013). The latter approach, i.e. musculoskeletal modeling, consisting of software such as AnyBody Modeling Systems (AMS), uses mathematical modeling techniques to simulate the diverse muscles and bones in the human musculoskeletal structure. Muscles are modeled as contractile force generating elements, while bones as rigid elements. Each muscle in the model is assigned a strength based on its size and its contribution towards performing a work task is determined by the solution of an optimization problem in an inverse dynamics analysis (Damsgaard et al., 2006). The ratio between the muscle contribution and its corresponding strength, that is the muscle activation level, has been used to compare the acceptability of alternative workplace layouts (Pontonnier et al., 2014; Xu et al., 2016).

---

* Corresponding author.
E-mail address: chander.divyaksh@polito.it (D.S. Chander).

https://doi.org/10.1016/j.apergo.2017.09.015
0003-6870/

There are clear differences between empirical-statistical and musculoskeletal modeling approaches to estimate the strength of the digital human. The reliability of empirical-statistical models depends significantly on the breadth of the empirical observations as a variety of working conditions can be observed in the workplace. Therefore, a crucial concern with the empirical-statistical model based DHM tools is how they extrapolate the strength to conditions that were not part of the observed set. On the other hand, musculoskeletal model based DHM tools should be able to account for this diversity in the working conditions if they represent a detailed and more realistic model of the human musculoskeletal structure. The key aspects of musculoskeletal models are the accuracy of the muscle models and the correct utilization of muscles in a given task. The human body consists of more muscles than necessary to perform a task. Therefore, it is fundamental that the model simulates correctly the criterion selected by the central nervous system (CNS) to decide the utilization of the various muscles to perform a given task.

In this work, we attempt to assess the usability of AMS as a tool for workplace optimization. The utility of a proactive tool for workplace optimization would depend on the accuracy of the predicted force exertion capability, the convenience in setting the mannequin into desired postures, and the scaling of the strength to represent different population percentiles. The aim of this work is to serve as a first step to investigate the reliability of defining favorable directions of force exertion at different work points through AMS to support virtual workplace optimization. In other words, we would like to verify if the human model of AMS could reliably account for the variation in the human force exertion capability due to changes in the work location and exertion direction. We would use the isometric strength at the hand as a measure of the force exertion ability due to the vast existing literature and ease in simulation. The existing work using AMS in simulations of isometric force exertion is focused on unidirectional exertions. Bassani et al. (2017) and Rajaee et al. (2015) simulated lifting loads to compare the predicted lumbar intradiscal pressure with *in vivo* measurements. Duprey et al. (2015) simulated the medial force at the hand during a hose insertion task. Oomen et al. (2015) developed a rule for strength scaling based on the knee extension strength and validated the simulated leg press strengths using this rule. While AMS has shown good results in these specific applications, the behavior of AMS in a general application of multi-directional isometric force exertions is unknown to the best of the authors' knowledge.

For its use as a tool for workplace optimization, it would be useful if the human model of AMS can represent a population sample. The use of population sample is important as ergonomists usually compare task requirements with the capabilities of the population to estimate the risk of WMSDs (La Delfa and Potvin, 2017). Therefore, we would use the average strength, anthropometric and posture data of a population sample as a reference for the simulations. The approach for modeling the population strength is different from modeling individual strength, which requires detailed subject-specific data, beyond the usual anthropometric variables (Oomen et al., 2015). Thus, the purpose of the present study is to evaluate whether the multi-directional force exertion capability in the workspace, as assessed by the AMS human model, can reliably simulate the strength capabilities of a population sample.

2. Material and methods

As this work focused on the isometric strength assessments of AMS in the workspace, it was important to have detailed knowledge and to reproduce the postures of the subjects to reduce the variation in strength due to unequal postures. We searched existing strength databases in the literature to use as a reference for the simulations. However, several multi-directional strength databases lacked specific postural information such as the joint angles assumed by the subjects during the trials. La Delfa and Potvin (2016), Roman-Liu and Tokarski (2005) and the master's thesis of La Delfa (2011) provided such strength databases with explicit postural information. Roman-Liu and Tokarski (2005) measured gripping, lifting, and pushing forces and torques of pronation and supination. This was a limited set of exertions when compared to (La Delfa and Potvin, 2016) and La Delfa (2011), both of which measured force exertion in 26 directions at eight hand locations. Between both of these works, La Delfa (2011) had a more extensive posture database encompassing all the test conditions (8 hand locations * 26 directions = 208) by averaging the joint angles across the subjects only. Instead, La Delfa and Potvin (2016) provided the same joint angles at only the eight hand locations, averaging across subjects as well as exertion directions at every hand location. Additionally, the subjects were standing during the strength tests in La Delfa (2011). Whereas, in La Delfa and Potvin (2016), the subjects were seated during the trials. The use of a seat would allow the subjects to brace themselves against the additional surfaces of the seat, augmenting the strength in directions favorable to such bracing. Simulating such an interaction would introduce additional uncertainties in the results of the simulation. Consequently, La Delfa (2011) was selected as the reference database. This database provided the necessary information to develop the simulations in AMS. A summary of the key aspects of these experiments is provided in this section. For more details, the reader is referred to the original work of La Delfa (2011).

2.1. Experimental data

Seventeen right-handed female subjects were recruited for the experiments that required them to exert maximal isometric force using their right hand in a standing posture while using their left hand to support and brace themselves during the exertion. The mean height of these subjects was 167.7 cm (SD ± 6.8), the mean weight was 62.5 kg (SD ± 10.9), and the mean age was 24 years (SD ± 1.8).

The eight hand locations in these experiments were defined using the height of the hand relative to the body and the horizontal hand angle (Fig. 1a). The hand heights (overhead, shoulder, and umbilicus) were uniquely defined for every subject, considering their respective anthropometry. The horizontal hand angles (0°, 45°, and 90°) were the angles that a vertical plane passing through the hand and the shoulder subtended with a sagittal plane through the shoulder. The eight hand locations used in the experiments were Overhead 0°, Overhead 45°, Shoulder 0°, Shoulder 45°, Shoulder 90°, Umbilicus 0°, Umbilicus 45°, and Umbilicus 90°. The third coordinate of the hand location, that is the distance of the hand from the shoulder, was defined as 80% of the maximum arm reach.

At each hand location, the subjects exerted force in 26 directions. These 26 directions were classified as one-dimensional (1D), two-dimensional (2D) or three-dimensional (3D). 1D directions were the six primary directions (Superior, Inferior, Anterior, Posterior, Medial, and Lateral). 2D and 3D directions were the combinations of two or three of these 1D directions, respectively (La Delfa and Potvin, 2016). We adopted the same naming convention for force exertion directions in this work and they are illustrated in Fig. 1b.

Force or manual arm strength (MAS) of the subjects was measured using a triaxial load cell mounted with a vertically oriented handle. A live feedback was provided to the subjects during