CHAPTER XX

A biomechanical evaluation of dynamic and asymmetric lifting using the AnyBody™ commercial software: a pilot study

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ABSTRACT

A six-camera motion capture (mocap) system collected dynamic motion data of lifting 30 lb (13.6 kg) weight at 0º, 30º and 60º asymmetry. The mocap data drove the AnyBody™ model, and the study investigated the effect of the asymmetry. Erector spinae was the most activated muscle for both symmetric and asymmetric lifting. When lifting origin became more asymmetric toward right, erector spinae activity was reduced, but oblique muscles increased their share of activity to counter the external moment. Most muscle tensions peaked at the lift initiation phase except left external oblique and right internal oblique. Left external oblique played a minor role in the right asymmetric lifting task, and the difference of activation for right internal oblique may be due to variance of the motion. Surprisingly the lift asymmetry decreased both compression and shear forces at the L5/S1 joint. This finding contradicted the results obtained from other research studies. The reduction in spine forces is postulated to have resulted from the increased oblique muscles' share in the production of back extensor moment. Since these muscles have longer moment arms, they generated lesser spine force to counteract the external moment. The subject also tended to squat as lifting origin became asymmetric, which effectively reduced the load moment on the spine. This factor might also have contributed to reducing spine forces during asymmetric lifting.

Keywords: biomechanical evaluation, asymmetric lifting, AnyBody™ modeling, spinal forces

1 INTRODUCTION

Asymmetric and dynamic lifting occurs in a great variety of workstations, and it is known to be one of the leading causes of occupational lower back disorders (LBDs). Occupational LBDs is a manifestation from overloading of back extensor muscle and spinal tissues during lifting. Biomechanical modeling has been utilized to investigate lifting task characteristics so that the task demands can be kept within a limit, and internal muscles and joints are not injured.

EMG assisted biomechanical models (McGill and Norman, 1986, Marras and Granata, 1997) were developed under the concept that the muscle tension correlates well with the electrode potential. Another category of model, optimization criterion based, assumes that muscles are recruited in such a way that a criterion function is minimized to reduce a biological cost, such as joint compression force (Schultz and Anderson, 1981, Bean et al., 1988) and muscle fatigue functions (Arjmand and Shirazi-Adl, 2006b, Rasmussen et al., 2001, Chung et al., 1998).

A detailed anatomical model of the lower back is beneficial to both categories of models. Current anatomical models of the lower back can not only consider all major muscle groups relevant in lifting activity, but also the muscle model can differentiate individual muscle fascicles of the individual muscle group (Arjmand and Shirazi-Adl, 2006a, de Zee et al., 2007) with consideration of muscle wrapping against bony structures (McGill and Norman, 1986, Nussbaum and Chaffin, 1996, Arjmand and Shirazi-Adl, 2006a, de Zee et al., 2007).

The AnyBody™ Modeling System is commercially available, optimization criterion based modeling software. It provides by far the most detailed human torso musculoskeletal model. The torso model of AnyBody™ has been utilized effectively to validate internal muscle and joint forces (Grujicic et al., 2010, Wu et al., 2009b, Wu et al., 2009a, Wu et al., 2008), but none of the studies investigated the effect of asymmetric and dynamic aspects of lifting. This study implemented AnyBody™ to analyze internal torso loading in asymmetric and dynamic lifting tasks.

2 METHODS AND MATERIALS

One healthy college student (1.73cm, 75kg) without any history of LBD during the past six months performed asymmetric lifting tasks of 0°, 30° and 60° with 30lb (13.6kg) dumbbell weights, placed evenly in a plastic tray, in OptiTrack™ mocap Laboratory. The lift origin was fixed at knuckle height (99cm off the ground), and at a horizontal distance of 53cm from the center of the tray to the vertical body axis, which was dimensionally identical with Marras and Davis's study (Marras and Davis, 1998), so that the results could be compared. Asymmetric angles were taped on a force plate for feet positioning, including a sagittal symmetric position (0°), 30° and 60° to the right of the mid-sagittal plane. The force plate was used to collect ground reaction data during the lifting. The force plate data were not used in this study, but will be used later to check the validity of AnyBody™ model (Figure 1).

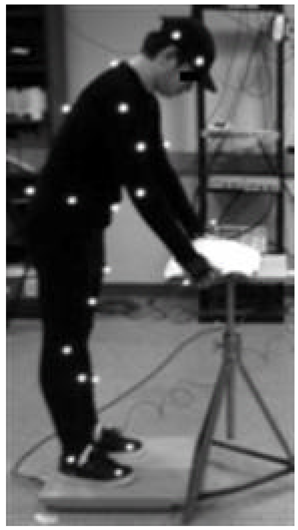

Figure 1 Asymmetric lifting task configuration.

Before the experiment, the participant put on the OptiTrack™ medium-size mocap suit. With the help of laboratory assistant, thirty-four reflective markers were attached on the suit based on OptiTrack™ standard thirty-four-marker placement protocol (NaturalPoint Inc., 2011). After standard calibration and skeleton setting up procedure instructed by ARENA™ mocap software (NaturalPoint Inc., 2011), the motion data of lifting were collected through OptiTrack™ six-camera tripod setup (NaturalPoint Inc., 2011) with 100 frames/seconds. A thin metal stand supported the plastic tray with dumbbell weight to prevent marker blocking. During the experiment, the participant performed 0°, 30° and 60° lifting tasks in a randomized order. The participant stood straight with feet along with the tape of pre-defined angle, and lifted from the lift origin to upright position without moving feet.

ARENA™ software automatically filled missing frames less than 20, and smoothed data with cut-off frequency of 6 Hz. Gaps more than twenty frames were filled manually by visual inspection. The ".c3d" files were further trunked to capture the lifting activity only. Approximately between 160 to 220 frames were generated by ARENA™ for individual trials. Figure 2 shows the first frames of 0°, 30° and 60° asymmetric lifting simulated in inverse dynamic study by AnyBody™ model respectively.

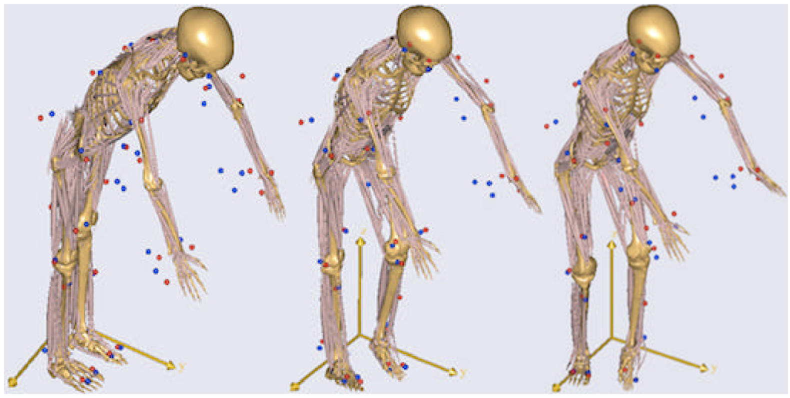

Figure 2 First frames of 0°, 30° and 60° asymmetric lifting initialized in inverse dynamic study by AnyBody™ model.

GaitLowerExtremityProject model in AnyBody's Managed Model Repository1.31 was modified for the experimental task. Because pre-defined marker placement in AnyBody™ is different from reality, parameter and motion optimization algorithm was run before inverse dynamic calculation within AnyBody™ software. On a Sony VAIO® E series laptop computer with 2.2 GHz dual-core CPU and 3GB RAM, inverse dynamic calculation took about 40 second/frame, but parameter and motion optimization lasted for hours depending how accurate the initial marker placement is.

3 RESULTS

3.1 Muscle forces

AnyBody™ models muscle fibers in each muscle fascicles, for example, erector spinae is divided into a total of 29 fascicles on each side (de Zee et al., 2007). To obtain the approximate contribution by each muscle group, the fascicle forces were summed over the normalized duration of lifts (Figure 3).

ES was the most activated muscle for both symmetric and asymmetric lifting. Generally, RES and LES became less activity as the lifting became more asymmetric. Oblique muscles became more active as the lifting became more asymmetric. Majority of the muscles were most active during the lift initiation phase, with exceptions for LEO and RIO. Since at the lift origin the load is farthest from the spine, as well as the upper body is maximally bent, the stronger muscle activity is expected. LEO played a minor role in right asymmetric lifting task, and the difference of activation for RIO may be due to variance of the motion.

However, some observations cannot be properly explained. The zig-zag pattern of oblique activation may be due to the dynamic effect of lifts, resolution of mocap, or error tolerance of AnyBody™ calculation. More data from different subjects need be collected for conclusive results. The more oblique forces for 0° or 30° than 60° at certain instances were also not explainable.

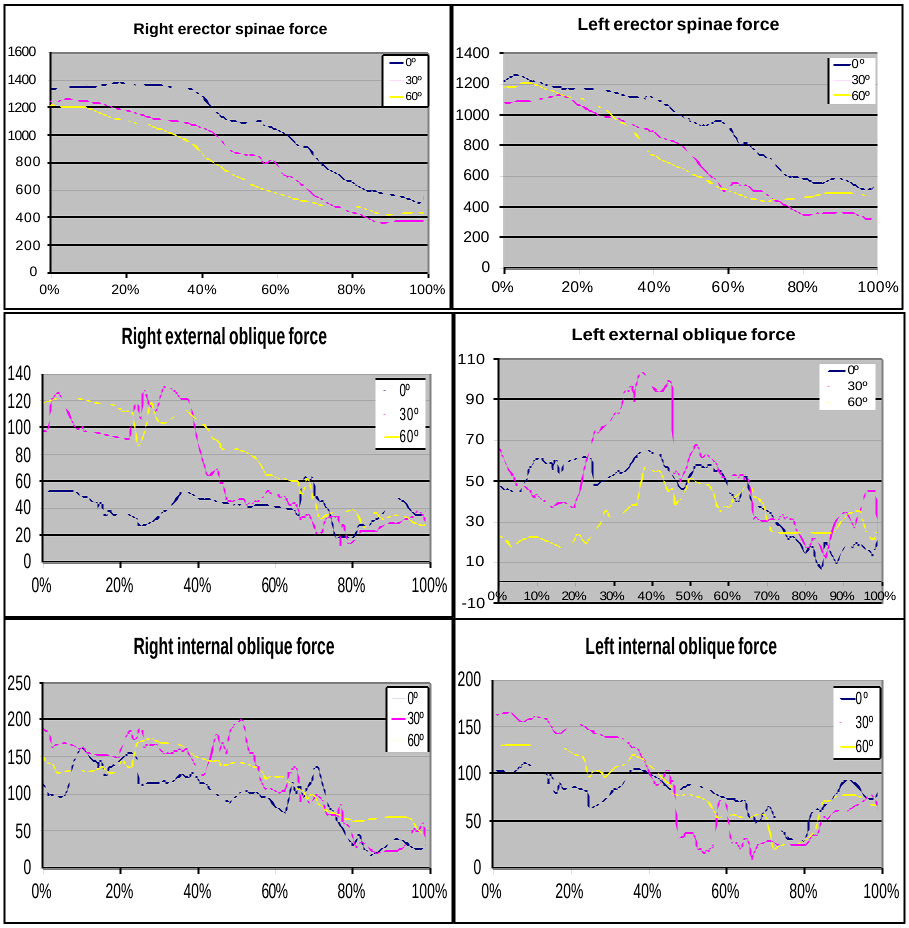

Figure 3 Right erector spinae (RES), left erector spinae (LES), right external oblique (REO), left external oblique (LEO), right internal oblique (RIO), left internal oblique (LIO) force development during the lifting

3.2 L5/S1 joint forces

L5/S1 joint compression, anterior-posterior (A-P) shear and lateral shear forces over the normalized duration of lifts are presented in Figure 4. Compression and A-P shear forces followed the similar pattern, which was identical with ES muscle forces. At the beginning and the end of lifting, the joint loads were steadier than between, probably due to the requirement of movement control. Comparing with 0° lifts, L5/L1 maximum compression force reduced from 3156N to 2963N by 6.1%

and 2888N by 8.5% for 30° and 60° respectively; maximum A-P shear force increased 2.3% to 568N for 30°, but reduced 6.5% to 519N for 60° respectively comparing with 0° from 555N; absolute lateral shear force reduced from 52.6N for 0° to 44.6N by 15.2% and to 23.8N by 54.8% for 30° and 60° respectively. In general, joint forces reduced as lifting origin became more asymmetric.

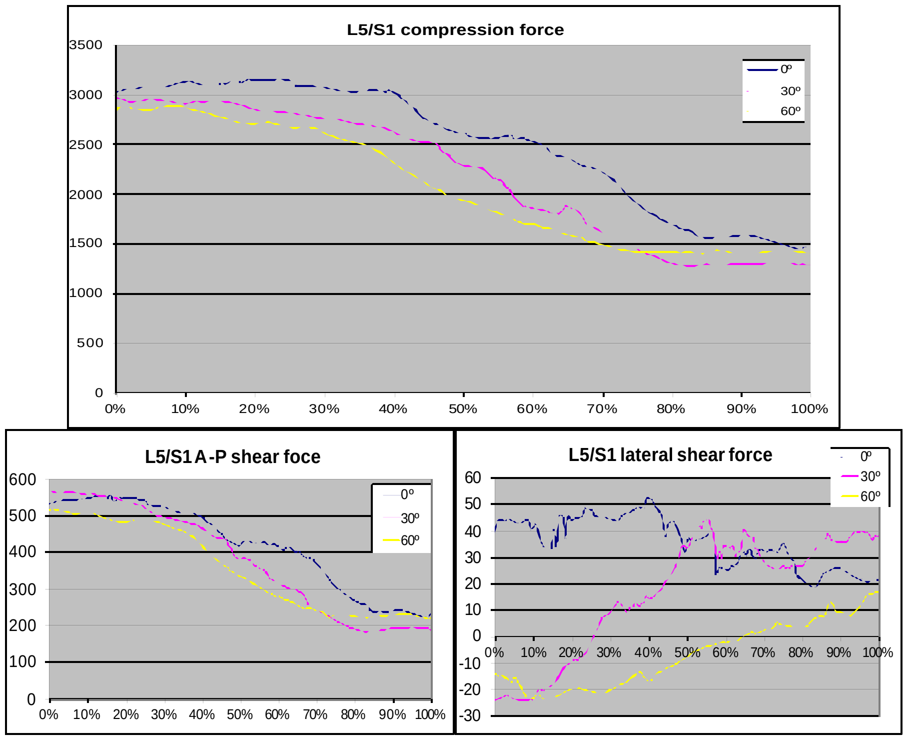

Figure 4 L5/S1 compression, anterior-posterior (A-P) shear and lateral shear forces during the lifting

4 DISCUSSION & CONCLUSION

ES is the main extensor of trunk. When the ES fascicles of one side act together, they produce combined lateral flexion and rotation to the same side (Palastanga et al., 2002). During asymmetric lifts, the support of the external load is shifted from the large ES muscles to smaller, less capable oblique muscles (Marras and Mirka, 1992). Biomechanically, ES has smaller moment arm than oblique muscles referring to lumber joint, so ES is less efficient to support external moment generated by upper body weight and hand loads. When the support of the external moment shifts from ES to oblique muscles, which also means shifting to more efficient muscles, the joint forces should reduce. However, oblique muscles are much weaker than ES, so they are less activated during symmetric lifting to minimize muscle fatigue. Furthermore, from observation (Figure 2), the participant tended to squat more as lifting origin became more asymmetric, which may also be a strategy of our body to reduce joint forces.

According to NIOSH (NIOSH, 1981), the tolerance level for compression loading of the spine is expected to be around 3400 N. At this level of compression, micro fractures of the vertebral endplate begin to occur. The threshold limits for spine lateral and A-P shear are probably less than 900 N (Marras and Davis, 1998). Reducing A-P shear and compressive forces should be considered a priority to prevent LBDs (Marras and Davis, 1998). In this study, joint forces did not exceed the limitation. However, if certain factors such as lifting speed, lifting height and lifting weight become more demanding, joint forces may exceed the tolerance level, and long time working under those circumstances may develop LBDs.

The average maximum L5/S1 compression force derived from ten subjects by Marras et al.'s EMG assisted model (Marras and Davis, 1998) was 3600N, 3900N and 4050N for asymmetric lifting of 0°, 30° and 60° toward right, which was presented graphically. Compression forces increased as the lifting origin became more asymmetric, which was contradicted with this study. A-P shear force was approximately 910N, 850N and 830N for 0°, 30° and 60° asymmetry respectively. Comparing with this study, both A-P shear force deceased as the lifting origin became increasingly asymmetric, but the force predicted by Marras et al. was about 350N higher than this study. Lateral shear force predicted by them ranged from 210N to 350N, which was far higher than the values predicted by AnyBody™ in this study. Generally, they found compression and lateral shear forces increased as the lift origin became more asymmetric, whereas A-P shear force decreased. The EMG assisted model is based on the assumption that the muscle tension correlates well with the electrode potential. This assumption should provide that the muscle contraction is isometric, that is muscle fiber lengths remain unchanged during force production (NIOSH, 1992). However during dynamic situation, when muscle fibers generates force as well as change their lengths, sliding action of muscle fibers underneath the fixed surface electrodes, also induces electrode potential (NIOSH, 1992). Unless the dynamic part of the electrode potential is separated from the gross electrode potential, EMG may not accurately estimate force generation by the muscle fibers.

Commercially available AnyBody™ biomechanical model provides by far the most detailed human anatomical model, which is driven by criterion optimization algorithm. To our knowledge, the model has been used for the first time to evaluate dynamic and asymmetric lifting. ES was the most activated muscle for both symmetric and asymmetric lifting. When lifting origin became more asymmetric toward right, ES activity was reduced, but oblique muscles increased their share of activity to counter the external moment. Most muscle tensions peaked at the lift initiation phase except left external oblique and right internal oblique. Surprisingly the lift asymmetry decreased both compressive and shear forces at the L5/S1 joint. This finding contradicted the results obtained from other research studies. More data from different subjects should be collected for a conclusive results, and force plate data should be used later to check the validity of AnyBody^{TM} model.

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