The Role of Quantitative Biomechanics in Understanding and Preventing Pathological Adaptations to Cumulative Work in the Upper Limbs

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INTRODUCTION

Work-related Cumulative Trauma Disorders [(CTD), also referred to variably as Repetitive Strain Injury (RSI), Work Related Musculoskeletal Disorder (WRMSD), Repetitive Motion Injury (RMI) and Occupational Overuse Syndrome (OOS)] are the fastest growing segment of reported injury in most of the developed nations of the world. CTD refers to "a collective variety of painful, chronic neuromusculoskeletal disorders of the neck and upper limb" (MacKinnon and Novak, 1997). In the United States alone, it is estimated that the costs associated with these injuries exceeded $120 billion in 1994 (Occupational Safety and Health Administration (OSHA) PressRelease, 1996). The Bureau Of Labor Statistics (1996) indicated that 65% of the reported injuries could be accounted for by CTD. Two thirds of those related to the back while one third related to the upper quadrant. According to The Bureau Of Labor Statistics (1996), 92,576 claims were paid on cases of upper quadrant repetitive strain injuries that involved lost time from work. This does not likely even nearly account for the actual numbers of individuals affected who do not report the injury to the workplace, but manage it on their own (MacKinnon and Novak,1997). While these injuries are widely prevalent in the industrialized countries, they will become an increasing challenge to the developing nations that are embracing modern manufacturing and information management practices (Shahnavaz, 1994)

There have been several responses to the alarming rise in these types of injuries. Examples have included labeling sufferers as having "facetious" injuries that are a result of hysterical reactions to rapid social or workplace change (Reilly, 1995) or as injuries resulting from poorly conducted research, Research, they say that has failed to prove the existence of these disorders or bear out the dose-response relationship from work activity (Hadler, 1997). Another response has been a multi-million dollar attempt to invent products or processes that aim to reduce the cause(s) of CTD. This has resulted in hundreds of untested and poorly understood "solutions" being introduced to workplaces throughout the world. The central theme of an essay by Hadler (1997) is the lack of sufficient science to support the existence of the CTDs. In the U.S., OSHA has been attempting to pass through congress, for nearly three years, an ergonomics regulation that features standards and compliance measures for employers. It has been turned back in the face of a powerful business lobby and a demand for more scientific proof of the hazard (OSHA Press Release, 1996). The result of this approach has been a very undirected discussion with empty diagnoses and hit and miss, ideologically biased approaches to prevention (e.g. Sorehand, ErgoWeb Listserv, 1995 - 97, Proceedings of the Silicon Valley Ergonomics Conference, 1996).

The study of biomechanics, along with work physiology, has been at the centre of investigating the impacts of workplace health and safety for decades. It holds great promise as the science that can shed clear light on the issues described in the foregoing through the development of the understanding of underlying mechanisms of these injuries. This would differ from the heavy focus in most publications on the multi-factorial influenced outcome of pain or complex regional impairment. In fact, biomechanics already has delivered valuable information and perspective, to some extent, as evidenced in the following. The question remains as to what more can a quantitative approach to biomechanics research aid us in understanding the causes and prevention of CTD?

I conducted a partial literature review using Medline, ErgoWeb and the ‘Abstracts in Ergonomics’ indices. In this paper I will review the role that biomechanics has played to this point in understanding and preventing CTD of the upper limbs. This will include themes in the research as well as examples of each. It will also include a discussion of the potential mechanisms (i.e. kinematic analysis, forward dynamics modeling, EMG surveillance) within biomechanics that could and have assisted in the study of this issue. The central element of the paper will be the critical contrasting of two studies from peer-reviewed literature that demonstrate significantly different approaches to answering complex questions about CTDs. Biomechanics has and can continue to increased understanding of CTDs. The benefit to our changing society and the proper practices of workplace health and safety should be substantial in terms of both human and fiscal cost.

DEFINITIONS AND HISTORY

About CTDs

CTDs have been established as multi-factorial injuries by many sources including Mackinnon and Novak (1997) who describe these factors occurring in three areas:

1. Amount of Tissue Damage (relating to repetition, force, duration of exposure, position and vibration).

2. Individual Parameters (eg. age, systemic illness, obesity and physical fitness)

3. Psychosocial Factors (i.e. the individual’s balance between stress and coping mechanisms at home and work).

Armstrong et al (1993) have proposed a conceptual framework based upon a dose-response model that incorporates individual capacities as well as external exposures. It does not address the psychosocial factors, however. Both this model, its accompanying review of literature, and the MacKinnon and Novak (1997) review discuss the anatomical structures involved in CTDs. These injuries are either (although uncommonly) simple traumas involving single structures of muscle, connective tissue, nerve and occasionally bone or they are (more likely) complex involvements of many, if not all of the aforementioned structures.

Role of Biomechanics

The biomechanics of the human experience are self evidently linked to the psychosocial elements and is therefore an interdependent part of a complex paradigm. However, biomechanics is heavily involved in the understanding and prevention of the pathogenesis of the neural, connective, muscular and bony components of CTD injury. This has been recognized for some time, at least since the early 20th century (Tichauer, 1975) and spawned the subdiscipline of Occupational Biomechanics (Chaffin, 1987: Tichauer, 1975)). This has become a large contributor to the multidisciplinary pursuit of ergonomics. Ergonomics involves behavioral and engineering sciences with the life sciences to address issues facing people at work. An earlier example of that work included Tichauer's (1975) quantification of the Biomechanical Profile of wrist motion using myograms and electrokinesiometers. Another example was the delineation of the early generation of the NIOSH Lifting Equation that predicted acceptable L5/S1 disc compression values in 1981 (Chaffin, 1987). It was a highly simplified and 2-D model of spinal loading that has since been joined by sophisticated 3-D models that even correct for muscular co-contraction during axial twist and lateral flex movements (McGill et al, 1996). It is interesting to note that Tichauer suggested fifteen "Prerequisites of Biomechanical Work Tolerance" in 1973 that were based on valid scientific investigations that still hold true today, but have been partly ignored by current practices. Many of these advances and prediction equations are reviewed in Chaffin and Andersson's 1984 book, Occupational Biomechanics.

Reductionism or Systems Thinking?

Before advancing to the detailed examples of biomechanical investigations into CTDs, an important issue needs to be addressed. Overly reductionist approaches to scientific investigation have been roundly criticized for addressing issues and questions outside of their full context. Systems based approaches are preferred to conceptualize complex, multi-factorial, context dependent issues. However, in order to fully understand the systems perspective, fundamental work must be done to bring greater understanding of the many factors in the system. Proceeding with a systems view before understanding individual factors will multiply errors significantly (Senge, 1990). Once these factors are understood, the potential exists for the development of modeling simulations that would allow us to experiment with the manipulation of factors in a simulated, no-risk environment. CTD is definitely a complex interplay of factors as pointed out previously. Unfortunately, complex outcomes are being attributed to simple factors in complete ignorance of the self-evident context of complexity. Examples of this would include studies that choose perceived comfort to be the key outcome in two day to six week investigations. Even in the wide-ranging review article by Armstrong et al (1993), only 31 of 99 references were from fundamental scientific investigations, most were clinical observations and correlation's. What follows are descriptions of how quantitative biomechanics can and has assisted in the understanding of CTDs by focusing on fundamentals and progressing to the development of models. There are also some examples of poorly executed or reported investigations.

BIOMECHANICS INVESTIGATIONS

The following are a sampling of studies conducted in the area of occupational biomechanics demonstrating their contribution to the understanding of human movement and the implications for pathological adaptations to repetitive work. There are examples of a variety of approaches and techniques.

Electromyography (EMG)

EMG investigations are the most popular form of investigation of the biomechanics of CTDs in the literature, but are also suspect in some of their conclusions. A study will be presented in detail in the next section to address these suspicions. There are many excellent examples of either fine wire, needle or, more commonly, surface EMG research. These investigations are often carried out in combination with other techniques discussed below. EMG can deliver good information about muscle activation, force production and fatigue. The general problems in the literature include assumptions about the value of certain amplitudes of contraction relative normal function, use of surface electrodes to attempt to discern between upper trapezius and supraspinatus or individual forearm flexors and extensors. Wire electrodes are also used inappropriately from time to time in attributing measurement to an entire muscle.

An excellent example of an EMG study relating to injury prevention is with Luttman et al (1996) in their investigation of muscle fatigue during urological surgical procedures. By appropriately differentiating the signals they were able to determine the endurance time of the muscles and compare it to the surgical time exposures. When they did not compare favorably, a new endoscopic surgical technique was reviewed and found to be effective at reducing muscle fatigue. Another study (Veiersted et al, 1993) demonstrated a higher prospective risk of injury investigating EMG breaks in the upper back and neck of employees in a manufacturing plant. They discovered that workers with more frequent EMG gaps had a lower prospective incidence of neck myalgia. Extensive data has been produced McGill and Norman using EMG to understand the contribution of torso musculature to spinal biomechanics and the development of a valid a reliable model to predict load in the torso and spine specifically (McGill et al, 1996). Monitoring muscle activation and fatigue will continue to be of substantive importance to continued research since these tissues are centrally involved in movement and movement pathologies.

Statics Analysis

Statics analysis has been used to determine joint moments for different activities. It is essentially conducted by determining the product of the force and the lever arm. It can be effective for the analysis of purely static situations, but it misses some dramatic effects of acceleration and decelerations on moments in dynamic movement (Giroux and Lamontagne, 1992). A study conducted by Daams (1992) used statics principles to determine the comparison of moments exerted around one or more joints in the upper limb. He reported that the greater number of joints involved, the greater the moment generated, but the lower the joint force. This is valuable in understanding the effects of force coupling in work. Harding et al (1989) used a static 2-D mathematical model of human fingers in conjunction with a piezoelectric force transducer to determine the variation in joint reaction forces in the fingers during piano playing. They determined finger postures that minimized joint reaction forces and tendon tension while still being able to execute the required attack on the keyboard. Static analysis allows for reasonably quick and often conservative estimations of muscle forces required under different load conditions.

Dynamic Kinematic Analysis - Video Analysis

Dean and Bruwer (1995) examined the effects of direction, distance and speed on the utilization of the upper limbs. They used digitized video positional data to assess movement strategies. Their results suggest that speed and proximity of movement determine how much of the movement stays in which segment of the upper limb. If high speed or short distances are required, people in the study accomplished virtually all movement at the wrist joint. Slower movements involved more segments. It is believed that the lower inertial moment that has to be overcome at the wrist is the reason for this. There are potential implications for a correlation between typing speed and injury to the distal structures. Continued and increased use of video analysis will be important in quantifying positional data and proceeding to inverse dynamics analysis as discussed below.

Dynamic Kinematic Analysis - Electronic Goniometers

Marras and Schoenmarklin (1993) developed a special set of goniometers to measure movement in the wrists during manufacturing work. They postulated that Newton’s Second Law could partially explain the incidence of CTD in that rapid accelerations and high velocities contribute higher forces that are at least partially absorbed through frictional contact between tendons and their sheaths or against the carpal ligament. They found high acceleration and velocity values to discriminate for future increased risk of CTD. As a follow-up, Marras et al (1995) applied a similar methodology in assessing different orientations of grocery store check out/scanning operations. They found wrist accelerations to be unacceptably high in all configurations, but demonstrated that some designs did influence wrist motion effectively. This type of movement analysis is very effective for small joints that move at higher velocities and accelerations over smaller displacements of position. Film analysis is limited in this realm by speed of the film and obscured views in many activities.

Dynamic Kinematic Analysis - Film (Inverse Dynamics)

There are not a large number of investigations in the literature that utilize inverse dynamics to understand joint moments in upper limb movements. There would also be the ability to progress the equations through to develop power and work information for single joints and across multiple joints. This could lead to an increased understanding of force-coupling relationships between joints and between the external load and the person. This information has been developed for total body lifting as in the study by De Looze at al (1992) where three different methods were compared in estimating total power. The study of Olympic Weightlifting has long utilized these methods when exploring the relationship between technique and economy or efficiency of movement. The study detailed in the A STUDY IN CONTRASTS section by Giroux and Lamontagne (1992) uses inverse dynamics in combination with EMG surveillance to calculate net moments at the gleno-humeral joint for a submaximal work task.

Mathematical Modeling

There are a number of different anatomical models to describe various kinematics at different joints in the body including those of the upper limb. This area of biomechanics holds great promise for the study of upper limb disorders as it allows investigators to manipulate one or many different variables in a simulated environment to predict virtual outcomes. In conditions that can lead to human injury this type of investigation is critical. The difficulty with models of complex mechanisms is the assumptions that are made in developing them and in validating them. Hawkins and Hull (1993) developed a fibre-based muscle model that also incorporates the effects of muscular fatigue. Muscle force is calculated as the sum of individual fibre forces based upon fibre kinematics and activation information. For their model, they assumed that there were three different fibre types and detailed fatigue data specific to those fibre types, gathered from previous studies, was factored in. This is an example of a very detailed model that takes into account not only pennation angle and maximum force generating capabilities of fibres, but also the viscous drag force created by the non-active fibres as they are dragged through the sarcoplasm during contraction. In the fatigue component it takes into account both central and peripheral neural control of activation (in final effect) and considers the average amount of available glycogen in different individual fibre types.

This model was validated against repetitive triceps work and the equations were found to be valid for times less than 50 seconds in isometric tests and 40 seconds in dynamic tests. After these times, the model overestimated muscle force for a given time. The authors postulate that this may be due to a more rapid decline in oxidative capability in slow twitch muscle fibre than is modeled since the Type IIb fibres are not contracting after 40 seconds in a maximal effort. The discussion of the model is thorough and although there are many assumptions, most of them have been carefully accounted for in the net effect of the model so as to render many of them inconsequential. This model is the first attempt to seriously include fatigue in muscle modeling along with other variables such as muscle length, shortening velocity, neural architecture and muscle architecture. Further work in this area, fed by research using other techniques, will be very important in beginning to understand the effect of factor manipulations on the entire system.

STUDY IN CONTRASTS

The following two studies are evidence of ineffective and effective biomechanics research in attempting to understand CTDs.

Case #1 - Electromyographic signs of shoulder muscle fatigue in repetitive arm work paced by the Methods-Time Measurement (MTM) system by G. Sundelin and M. Hagberg 1992

Purpose

The stated objective of the study was to investigate whether fatigue indicated by changes in EMG amplitude and spectral variables develops in shoulder and neck muscles in MTM-paced work. The investigators were attempting to replicate a driven (throughput quota) assembly environment where CTD-type injuries are common occurrences. They designed it in this way based on the suspicion that fatigue is a large part of the injury problem.

Methodology

In a laboratory setting, six healthy female students performed repetitive arm work continually for one hour. The work involved grasping a small cylinder (15g) from a box high enough to produce near 90 degrees of shoulder flexion, bring it towards the body and deposit through a small hole in the table. The work pace was set so that the cycle time for the movement was 1.46 seconds. Training was provided and the testing occurred in the afternoon. They were all seated with the hips and knees comfortably at 90 degrees.

EMG activity was recorded using surface electrodes on the lateral cervical portions of the right trapezius muscle and on the infraspinatus muscle. Electrode placement was spaced to avoid crosstalk. EMG was amplified linearly with a bandwidth of 5 - 500 Hz. Maximal elevation and external rotation strength was measured with a strain gauge and simultaneous EMG before commencing the experiment.

Fast Fourier Transform technique was used to obtain power spectral density function for an average time of 250 ms with a bandwidth of 10 - 500 Hz. Mean power frequency (MPF) and root means squared (rms) values of the amplitudes were calculated for the entire work period. Increasing rms and decreasing MPF was seen as an indicator of muscle fatigue.

Results

With respect to muscle load, the lateral trapezius muscle demonstrated a mean peak load of 31% of Reference Voluntary Contractions (RVC) and a static load of 4.4%. The cervical portion of the trapezius demonstrated 37% and 17% respectively and infraspinatus 55% and 12%.

With respect to fatigue, there was considerable variability among the subjects although they all displayed negative slopes in MPF in all three locations, especially in the lateral trapezius. Signs of fatigue were not found for all subjects in the cervical portion of the trapezius even though the static load was higher and only two of the six demonstrated fatigue in the infraspinatus.

Critical Discussion

There are a number of concerns with this study and they are itemized as follows:

1. Only six subjects were used. This created uncertainty in the fatigue data when some had negative slopes for both rms and MPF.

2. The assumption that the lateral trapezius electrode was not also receiving a signal from supraspinatus which would explain higher levels of activation. Both supraspinatus and the lateral trapezius would be synergistically coactivated in a movement pattern with arm abduction and flexion.

3. None of the prime movers (i.e anterior deltoid) were monitored in the study.

4. The discussion boldly states that dynamic activity doesn't seem to mitigate fatigue as follows: "It is therefore suggested that dynamic work movements do not protect the muscles in the shoulders and neck from fatiguing processes in highly repetitive work with short cycle times". Investigators did not collect data from dynamic muscles used in the activity. The cycle time was so brief as to make it impossible for relaxation of the shoulder girdle to occur. The movement required was guaranteed to develop high levels of fatigue and constant stabilization because of the geometry of the task.

5. Lateral trapezius had a static load of 4.4% RVC. Much is made of these low ongoing static loads in EMG literature relative to pathological levels of fatigue, but there is no identification of appropriate loading frequency or amplitude, no experimentation with biomechanically efficient movement patterns and no discussion of the impacts on subclavicular structures (i.e. brachial plexus) in the absence of trapezius activation. Furthermore, Waerstad and Westgaard (1996) found similar static loads in the trapezius during visual attention tasks with no other physical activity present. Attention appears to cause static load.

Although the investigators succeeded in acquiring the information they set out for, the total design of the experiment significantly limits its value. The collection and processing of data all appeared to be uncorrupted and well-considered, but the conclusions drawn from the study about dynamic movement are a great concern. It is a great concern because increased dynamic movement would be expected to mitigate the effects of CTD development. If it doesn't, it must be demonstrated in a more directed study than this one. EMG can be a very effective tool in understanding human movement more completely, but the study design and interpretation of data must be carefully considered.

Case #2 - Net Shoulder joint moment and muscular activity during light weight-handling at different displacements and frequencies by B. Gerioux and M. Lamontagne 1992

Purpose

The authors indicated that their reason for pursuing this investigation was a better understanding of the impact of dynamic movements at the shoulder and upper limb on cervicobrachial load as this loading is associated with pathological adaptations in workers executing repetitive tasks. They found, as did I in my literature search, that there is a large void in the literature with respect to dynamic loading analysis at the shoulder and upper limb. A significant additional benefit to this investigation, not mentioned by the authors, is the tendency, by the analysts of modern work, to discount the mass of the upper limbs and the moments that they contribute to. As an example, there is considerable attention paid to providing balancers for pneumatic tools on assembly lines, but very little discussion about the loading of the shoulder each time the worker reaches up for the tool.

The stated purpose of the investigation was calculate net gleno-humeral joint moments from inverse dynamics and to measure muscular activity from six shoulder muscles (supraspinatus, infraspinatus, middle deltoid, anterior deltoid, trapezius and pectoralis major) during light weight handling at two different displacements (horizontal and vertical) and frequencies (40 and 60 cycles/min.) to simulate an occupational cervicobrachial working task (light weight displacement).

Methodology

Ten healthy male subjects were selected for the study. They were required to move, while seated, a known weight corresponding to 15% of the maximal lifted weight (MLW) for four different work conditions (horizontal displacement - 40 cycles/min., horizontal displacement - 60 cycles/min., vertical displacement - 40 cycles/min., vertical displacement - 60 cycles/min.). They were all seated with the hips and knees comfortably at 90 degrees. Head and trunk movements were not permitted. Maximum voluntary contraction for EMG was determined by increasing loads until there was a disturbance in head or trunk position.

Both displacement tasks occurred in the sagital plane with the horizontal task involving the movement of an object (15%MWL) positioned 10 cm from the table edge to a position equal to 50% of the length of the subject's upper limb. The vertical displacement task required the subject to move the same object from the same starting point to a shelf at a vertical distance representing 75% of the subjects trunk length (shoulder to hip) and a horizontal distance equivalent to that moved in the purely horizontal task. The distance traveled by the upper limbs centre of gravity was approximately 15% longer in the vertical displacement task. Movement speed was controlled by a metronome.

Each task had a warm-up of 1 min. and 5 min. rest between conditions. EMG and cinematographic data were collected from three trials of 6 seconds each for each condition. The camera was placed

11.80m from the subject and oriented perpendicular to the plane of motion. Movement was recorded at 50 frames/sec. EMG data was collected through surface electrodes and intramuscular electrodes inserted into the motor control points of the muscles. Noise was monitored and excessively noisy electrodes were replaced. All electrodes were taped to limit movement artifact. The signals were recorded at 1000 Hz for 6 s in each condition. The signals were passed through a self made amplifier with a bandpass of 10 - 700 Hz. EMG was then converted to linear envelope and the rectified signals were filtered through a second order critically damped filter with a cutoff of 3 Hz. data was normalized time (% cycle) and amplitude (% isometric MVC).

Three cycles per condition per subject were digitized, shoulder angular velocities and net joint moments were calculated by inverse dynamics (normalized by time and averaged across subjects) using the BIOMECH package. The movement was divided into a flexion component and extension component.

Seven two-way factorial analysis of variance models were computed with EMG from each muscle and the integrated normalized shoulder moments as dependent variables and displacements and frequencies as independent variables.

Results

Net Joint Moment Analysis - The first 52% of the cycle corresponded to shoulder flexion and elbow extension while the last 48% corresponded to shoulder extension and elbow flexion. Net gleno-humeral moments reached their maximum in all conditions at the furthest point of reach. The peak net joint moment was higher in 40 cycles/min. activity. Moments were higher during changes of direction. Shoulder moment power analysis demonstrated concentric work in the first 52% and eccentric work in the final 48% of the movement. Higher moment powers were generated by the vertical displacements and the 60 cycle/min. frequency. These increases appeared to be as much as 100% higher at peak values.

EMG - Supraspinatus activity was as high as 40% MVC for the vertical high frequency condition during flexion and dropped to 25% during extension. The values were not much lower for horizontal (35% MVC) conditions. Infraspinatus was stable at 20%MVC in extension and 15% in flexion portion of cycle. Middle and anterior deltoid increase to approximately 50% MVC during the flexion component of the vertical conditions and drop to 30%MVC during horizontal displacement. It is stable at 10 - 15%MVC during extension of the shoulder. The upper trapezius was recruited at 30%MVC for the vertical displacement and at 15%MVC for the horizontal tasks (flexion components), frequency did not influence activation. There was considerable variability was measured throughout the movement (45 - 51%). Pectoralis major contracted at 25% during flexion and dropped to 10% during extension. There was a large variability of activation throughout the motion.

Supraspinatus and upper trapezius activity correlated highest with shoulder joint moment. Additionally, supraspinatus correlates very highly (0.89) with increasing vertical displacement (elevation and abduction of the shoulder).

Critical Discussion

The authors were very successful in generating the information they set out to understand. They actually uncovered a significant amount of interdependent information that could be utilized in better understanding CTDs. They make some specific work tolerance recommendations that are supported by earlier work. This study confirmed and further defined the responsibilities of the shoulder musculature in controlling shoulder position and forces in a dynamic condition.

It is interesting to note that the findings of this study were very much in agreement with previous work with the exception of one study that involved statics analysis. Supraspinatus obviously has a large role to play both as a mover in the shoulder complex and as a stabilizer. This study demonstrated that even horizontal displacements below 60 degrees of flexion produced similar activation of supraspinatus as in 100 degrees of flexion. This further encourages the maintenance of the arms close to the torso during work. This is an important finding that demonstrates that reaching of any kind exacts a large toll on supraspinatus.

In reviewing the methods of this investigation, some assumptions were made. Since the frequency cut-off was 3Hz, they were confident that the movement artifact would be curtailed by the taping of the electrodes. Other studies do not often go below 10 Hz (Veiersted et al, 1993) and actually suggest only movement artifact exists below 20 Hz. There is equipment available now that utilizes a Notch Filter to eliminate the movement artifact without removing potentially valuable frequencies (Noraxon, 1996). Strong steps were taken to guarantee the validity of the electrode placement. Another assumption that was made was that the movement was purely sagital and 2-D which of course it couldn't be. These effects were likely negligible in the result other than to perhaps explain higher signals from supraspinatus and middle deltoid which are abducting in both the vertical and horizontal task. Fifty frames per second is an appropriate speed for the movement speed which was maximum at 1Hz. This allowed the minimum collection of 50 frames of film for each cycle (25 in flexion, 25 in extension).

It would be tempting to suggest that the investigators use both higher and lower masses than 15% MWL to determine the impact. They suggest going higher, but going lower would also be of interest since many repetitive activities feature little more than the mass of the upper limb. In this study the mean mass lifted was 2.04 kg. They do not list the mean total body mass of the subjects so that a comparison between limb mass alone and limb mass plus external mass could be considered in order to weigh its importance. In an 80 kg person, the total arm mass would be approximately 5% (Winter, 1979) or 4.0 kg, so the loads lifted in this study are increasing limb load by approximately 50% in this example. Held loads increase the moment arm of resistance in activity.

Lower and much higher frequencies of movement would also be interesting to explore for their effects on muscle activation and joint loading. Another direction that may be valuable would be to analyze the impact on segmental moments and muscle activations (i.e. wrist elbow) using limb supports, braces or more innovative work postures. These experiments may serve to increase the error cost of the 2-D assumptions so that at some point a 3-D analysis may need to be considered in order to maintain validity.

Overall, this study was meticulously designed, carried out and chronicled. It allows the reader to see all the data (nearly all, see mass of subjects) and draw conclusions about the outcomes. They related their findings effectively to previous research and made sensible conclusions from the results. By comparison, the first study is illuminated as having asked a simple question about a complex system. The factor they were exploring, frequency was not found to be particularly relevant in the second study with relation to EMG activity. The first study did not consider the appropriate muscles although their findings with respect to both infraspinatus and upper trapezuis involvement are consistent with the second study reviewed. The critical difference is in the wide ranging interpretation of those results without wide ranging data.

CONCLUSION

Through the examination of the foregoing investigations it is clear that quantitative approaches to biomechanics using a variety of analyses can be very effective in increasing our understanding in preventing CTDs. They are focused on the underlying science of the issues so that sensible conclusions can be drawn from the processes and not just complex outcomes like comfort that don’t measure underlying processes. There are a number of research questions that could be answered in this way and there is already significant evidence that there is a physical hazard in repetitive work. There is not a huge population of research investigations in dynamic-integrated analysis as found in the Giroux and Lamontagne study. More would be helpful as would more comprehensive and sophisticated models. In 1975, Tichauer identified 15 strategies that would increase tolerance to work. They included avoidance of muscular insufficiency, keeping elbows down and keeping forward reaches short (Tichauer, 1975). These are still true today and were developed through careful understanding of the elements of normal human motion. That advice is still some of the most compelling in current ergonomics practice (although it is often ignored by some ergonomists and furniture manufacturers). Biomechanics can continue to answer these questions very effectively.

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