USING MOTION ANALYSIS TO AUGMENT
UPPER-LIMB PROSTHETICS OUTCOME MEASURES

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INTRODUCTION

As upper-limb prosthetic systems have become more sophisticated in terms of actuation and control, greater importance is being placed on producing movements of both the prosthesis and the user that have a more physiologically normative appearance. Reducing the degree or range of compensatory motions and improving the trajectory traversed in the movement of multi-joint prostheses are examples of design objectives to bring about better dynamic appearance. Standardized outcome measures in upper-limb prosthetics research and assessment generally do not provide objective information on the quality of movements performed by the prosthesis user. Without this type of information, it is difficult to evaluate different prosthesis designs for their impact on kinematics.

Early efforts to study the kinematics of human movement and apply the results to the design or understanding of arm prostheses were based on cinematography [1], [2]. However, digitizing sequences of individual movie frames to extract joint angles and trajectories was exacting and time consuming work and proved sufficiently daunting to limit its application. The replacement of film with magnetic videotape provided almost instantaneous access to the recorded image, but had little impact on the process of digitizing the individual images to extract the movement data. It was not until the advent of automatic motion capture with multi-camera systems recording the position of passive or active markers on the body that kinematic studies became widely attractive.

The point has been reached where motion data is, relatively speaking, easy to obtain and the problem of acquiring the data has been supplanted by questions of how can kinematic studies help our understanding, how much confidence can we have that the acquired data represents what we think it represents, and how best can the data be represented to provide insight into the important features of the movement under study.

ROLE OF KINEMATIC ANALYSIS

In 2009, the American Academy of Orthotists and Prosthetists convened a State-of-the-Science Conference on Upper Limb Prosthetic Outcome Measures [3]. The conference participants reviewed a variety of measures and assessment tools in use at the time and ranked the tools with regard to their methodological strength and field of application. None of the recommended outcome measures included motion-capture kinematic analysis. Furthermore, none of the measures ranked as “emerging”, “promising”, or “potential” incorporated motion-capture kinematic analysis. What, therefore, is the role for kinematic analysis?

Motion-capture kinematic analysis is not an outcome measure. It can be a measurement that when used in conjunction with a standardized outcome measure helps to clarify and enhance the understanding of results obtained from an outcome measure. Kinematic analysis provides objective information about the specific actions performed by an individual in carrying out a task.

Although kinematic analysis has the potential to aid our understanding of upper-limb prosthetic use and utilization, it is not without its caveats. Motion capture systems, widely used, require markers that are placed on the body. From the location of these markers, it is possible to approximate joint centers and segment lengths.

Ideally, markers should be anchored to the skeleton, but that is rarely feasible. Instead, markers are attached by adhesive to soft tissue overlying palpable skeletal structures. Skin movement that changes the location of the marker can alter the apparent location of a joint axis and/or change the apparent length of a limb segment.

There are several standardized marker sets that define where on the body markers should be placed for different kinematic analyses [4]. There are not, however, standardized sets that include prostheses, and investigators or clinicians are left to their own judgment as to where to place markers on prosthetic devices. Not only could different marker placements potentially alter results and confound inter-study comparisons, movement of the prosthesis on the residual limb could affect the apparent location of markers placed on a prosthesis. Pistoning or angular displacement of the socket, especially near the extremes of joint motion, could create a pseudo-arthritis, reducing the accuracy of the location of markers on the prosthesis with respect to markers on the body. For example, one study involving a subject with a transhumeral amputation who used a locking mechanical elbow was...
found to have a range of about 13° of elbow flexion when the elbow was locked [5]. The authors of that study attributed this finding to possible relative motion between the socket and the residual limb.

In addition to artifacts that affect apparent marker location, the subject may also behave differently while wearing markers and produce movements that are not representative of how the subject would move without the markers. Markers placed on the upper limb are readily visible. Their presence may distract the user or make the user guarded so as not to dislodge or bump a marker while performing a task.

**REPRESENTING MOTION DATA**

Motion-capture data—the sequential series of joint angles and limb and body segment positions sampled during an activity—can be further processed and reduced in various ways. One method is to calculate the angular range of motion during the activity for each joint of interest [5], [6], [7], [8]. The ranges, along with their minimum and maximum values, could be compared between subjects with intact limbs and subjects with impaired or prosthetic limbs doing the same task, or between subjects under different types of prosthesis. Differences in angular range of motion may reveal compensatory actions or effects of varying components or socket designs.

Ratios of angular ranges have been used to define asymmetry between right and left limbs used in a symmetrical bimanual task, such as picking up a box [7]. Ratios of angular ranges have also been used to highlight limitations of motion and compensation [8].

Data obtained during cyclic or repeated activities can be normalized with respect to where they occur in the cycle or at what percentage of time over the course of the activity they occur. [5], [7], [8], [9]. Normalization eliminates absolute time, enabling averaging of repeated data that occurred during shorter or longer periods for an individual subject and comparison of averaged data between subjects. Normalization can be used to compare angular profiles, trajectories, velocity profiles, and relative timing of coupled or uncoupled actions.

**CONCLUSIONS**

Kinematic data obtained from marker-based motion-capture systems has been used to reveal and highlight differences between actions performed by persons with intact upper limbs and persons with impaired upper limbs or with persons using arm prostheses. Although not an outcome measure in itself, kinematic analysis might be a powerful complement to standardized outcome measures, providing details about the movements used during functional tasks that individual outcome measures alone cannot convey. Attention to methodology and awareness of errors that prosthetic systems might introduce into kinematic analysis are important aspects for successful application.

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**REFERENCES**


