Compensatory motion caused by forearm restriction while turning a steering wheel for transradial prosthetic design

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Abstract

Poor function of a transradial prosthesis lacking a dynamic wrist component may cause awkward compensatory motion. The purpose of this study was to determine if the shoulder or elbow of the unaffected or affected upper limb compensates for the restriction of the wrist and forearm simulating a basic myoelectric transradial prosthesis while turning a steering wheel. Ten non-amputee subjects volunteered for this study. Using a Vicon motion analysis system, the subjects' upper limb movements were recorded while turning a steering wheel. This right turn was repeated with the subjects braced on the dominant (right) side restricting wrist and forearm movement. The range of the shoulder and elbow joint of the right and left sides were determined. A degree of asymmetry between the right and left arm was calculated. A repeated measure analysis of variance was calculated for each outcome measure comparing the non- braced (N-BR) and braced (BR) conditions. There were significant differences in the range of shoulder flexion and elbow flexion on right and left sides and in the degree of asymmetry. These findings suggest while turning a steering wheel, the braced or transradial prosthesis simulated side requires a greater range of motion in the sagittal plane of the shoulder and the elbow. This greater range of motion necessary should be considered in transradial prosthetic design.

Keywords: compensatory motion; turning task; transradial prosthesis

1 Background

Living in a country during wartime, the numbers of amputees including upper limb amputees will most likely increase. According to the Department of Veteran's Affairs, as of Feb. 2006 over 400 soldiers have suffered an amputation because of the casualties of war [1]. Below the elbow is where the majority of upper extremity amputations occur [2]. This level of amputation is called transradial. A transradial prosthesis can body powered using cables controlled by shoulder excursion or also myoelectrically controlled harnessing signals from electrodes attached to intact muscles. The range of motion of the upper limb of healthy subjects performing unilateral activities of daily living has been recorded and analyzed [3-4]. Other studies have examined common unilateral task completion of upper limbs while braced at the wrist [4], wearing a wrist splint [5] and using an upper-limb prosthetic simulator [6]. Weeks et al. studied the transfer of skills across limbs but not the effects of a bilateral task on upper-limb kinematics [6]. Bilateral tasks such as turning a steering wheel should be considered for upper limb prosthetic design.

2 Methods

2.1 Participants

Ten non-amputee volunteers with no history of upper limb injury (6 males, 4 females age 28 years, SD 7.4)) participated in this study. All the participants were right hand dominant. All subjects gave an informed consent prior to participation. The experimental procedures were approved by the Institutional Review Board of the University of South Florida before data collection.

2.2 Testing Protocol

An 8-camera infrared Vicon motion analysis system was used for the collection and analysis of movement data. Nineteen spherical reflective markers were placed on the boney landmarks of the upper limbs and torso of the subjects to describe segments as described in Table 1. A static trial and subject parameters such as shoulder depth, elbow width, wrist and hand thickness were collected to help determine joint centers. For each trial, the subject placed hands on the steering wheel at the "10 and 2" position. The subject was asked to self select the distance of the chair to the steering wheel similar to a feature available in most standard cars. The subject turned the steering wheel as far to the right as possible without removing hands and then returned the steering wheel to the starting position. The subjects were braced restricting the wrist and forearm movement as shown in Figure (1). The brace allowed for complete range of motion of the elbow, but did not permit pronation and supination of the forearm or flexion and extension of the wrist. The brace was an attempt to simulate the use of a transradial myoelectric prosthesis that lacks powered wrist and forearm movement. Three trials were collected for each experimental test condition. These three trials were averaged as a representative for each subject.

2.3 Kinematic Model

As explained in previous work by the authors, a kinematic model of the upper limbs and torso was created by the lead author using the Vicon Bodybuilder™ software [7]. The torso segment or local coordinate system was defined using the C7, T10, clavicle and sternum markers with the origin placed halfway between the C7 and clavicle markers, the x-axis. The upper arm segment was defined with the origin at the elbow joint center, calculated equidistant between the elbow lateral and medial markers during the static trial. The upper arm marker and the shoulder joint center, calculated using the shoulder marker and shoulder depth subject parameter to approximate the glenohumeral joint center, were also used to define the upper arm coordinate system. The forearm segment was defined with the origin located at the wrist joint center, calculated as the midpoint between the two wrist markers and using the elbow and shoulder joint centers.

Once local coordinate systems or segments were defined, relationships between the segments were determined. Joint angles were described as the relative orientation of two coordinate systems of segments next to each other. The shoulder joint angles were determined by how the upper arm segment moved in relationship to the torso segment. The elbow joint angles were calculated from the relationship of the upper arm segment to the forearm segment.

Table 1: Reflective marker placement

Marker description	Marker placement
C7	Spinous process of the 7th cervical vertebrae
T10	Spinous process of the 10th thoracic vertebrae
Clavicle	Jugular notch - the clavicles meet the sternum
Sternum	Xiphoid process of the sternum
Right back	Middle of the right scapula (asymmetrical)
Right shoulder	Right acromio-clavicular joint
Right upper arm	Right upper arm between the elbow and shoulder markers
Right elbow	Right lateral epicondyle approximating elbow joint axis
Right elbow medial	Right medial epicondyle (static trial only)
Right wrist A	Right wrist thumb side
Right wrist B	Right wrist 5th finger side –on the pisiform
Right finger	Dorsum of the hand below the head of the right 3rd metacarpal
Left shoulder	Left acromio-clavicular joint
Left upper arm	Left upper arm between the elbow and shoulder markers
Left elbow	Left lateral epicondyle approximating elbow joint axis
Left elbow medial	Left medial epicondyle (static trial only)
Left wrist A	Left wrist thumb side
Left wrist B	Left wrist 5th finger side
Left finger	On the dorsum of the hand just below the head of the left 3rd metacarpal

2.4 Data analysis

The study was a within subject repeated measures design and each subject repeated the task with and without a brace. The following outcome measures on both the right and left side were examined: range of shoulder flexion of glenohumeral joint, range of shoulder abduction, and range of elbow flexion. The range of motion was calculated by subtracting the minimum angle from the maximum angle. The peak pronation and supination of the forearm were calculated while the subjects completed the task without the brace. Using SPSS package (Ver. 14 for Windows), a repeated measure analysis of variance (ANOVA) was performed comparing the unbraced and braced conditions. The degree of asymmetry (DoA) between the right (dominant) side (R) and the left side (L) during this bilateral turning task was calculated with the following equation:

$$\frac{(L-R)}{(L+R)} \tag{1}$$

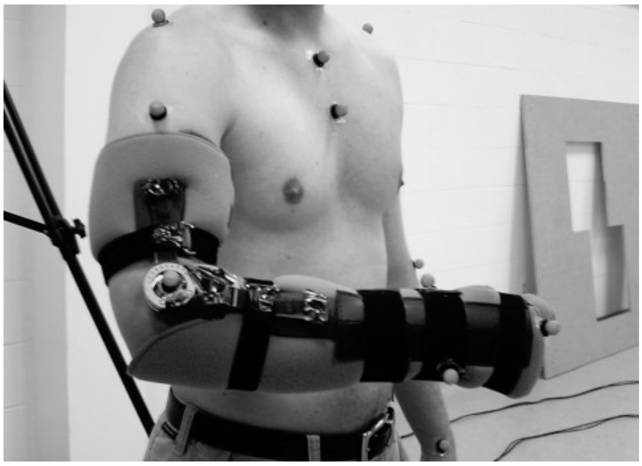


Figure 1: Brace and marker placement

The DoA was calculated for the range of shoulder flexion, shoulder abduction and elbow flexion. The value of zero represented perfect symmetry, a positive number and a negative number represented the left dominant asymmetry and right dominant asymmetry respectively. A repeated measure ANOVA was computed for the DoA for each range separately.

3 Results

The pronation and supination requirements of the forearm while turning a steering wheel to the right (dominant) side are shown in Table 2. The range motion of the right (affected) shoulder in flexion was significantly greater while braced (p=.007) when compared to the unbraced condition during this turning task. The range of motion of the left shoulder in flexion was significantly smaller while braced (p=.019). Similarly, the right elbow showed significantly greater flexion while braced (p =.02) while the left elbow showed significantly lower flexion (p =.006). The DoA of the range of shoulder flexion and elbow flexion also showed a statistically significant difference (p =.001), indicating a more right (affected) dominant asymmetry while braced.

	Right	Left
Pronation (degrees)	36 ± 12	63 ± 22
Supination (degrees)	75 ± 31	0

Table 2: Peak pronation and supination of control group (N=10) while turning a steering wheel to the right

Figure (2) shows an example of the shoulder flexion of one subject while turning a steering wheel non-braced and braced. It shows that during the braced condition the right (affected) shoulder moves through a greater range of flexion when compared to the non-braced trials. Oppositely, the left shoulder moves through a lesser range of flexion during the right arm braced trial when compared to the non-braced trial.

Figure 2. Right (affected) and left shoulder flexion of one subject during the non-braced and braced conditions while turning a steering wheel to the right.

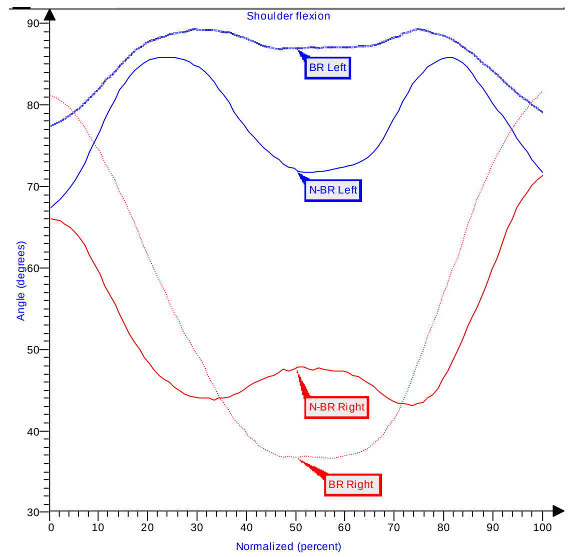
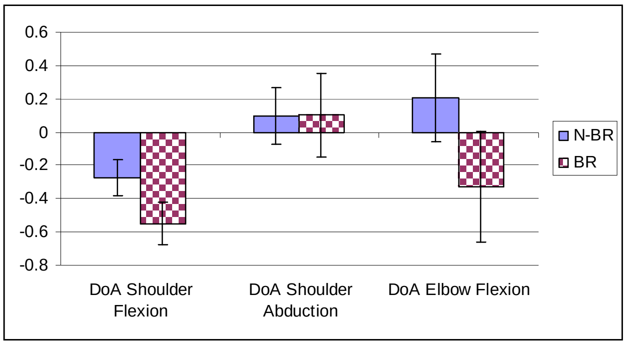


Table 3 shows the average and standard deviations of the ten subjects of all ranges of motions while turning a steering wheel with and without a brace. Statistical analysis also showed significant differences in the degree of asymmetry in shoulder and elbow flexion but not in shoulder abduction. The DoA of the shoulder and elbow flexion during the braced condition were negative values indicating a right dominant asymmetry as shown in Figure (3).

Range of motion (degrees)	No brace	Braced
Right shoulder flexion	39 ± 8	49 ± 5
Right shoulder abduction	26 ± 9	23 ± 10
Right elbow flexion	17 ± 5	29 ± 12
Left shoulder flexion	22 ± 6	15 ± 5
Left shoulder abduction	31 ± 7	27 ± 10
Left elbow flexion	29 ±13	14 ± 8

Table 3: Average ± standard deviation of range of motion of ten subjects during a right turn of the steering wheel

Figure 3: Averaged (N=10) degree of asymmetry while turning a steering wheel to the right



4 Discussion

Turning a steering wheel to the right requires flexing (Figure 2) and abducting the shoulders to hold the hands on the wheel. It also requires pronation of both forearms, supination of the right forearm (Table 2) and flexion of both elbows to produce the rotation of the wheel. Basic transradial myoelectric prostheses do not allow for pronation or supination of the forearm that is used to rotate the end effectors (hands) attached to the steering wheel. The results indicate that while braced simulating a transradial prosthesis, a greater range of shoulder flexion and elbow flexion were required from the braced or affected side while turning a steering wheel with two hands. Less range of motion was required from the left or unaffected side. This suggests that amputees using a basic transradial prosthesis may have to compensate for loss of movement of the forearm and wrist while turning a steering wheel by increasing shoulder and elbow flexion of the affected side. Moving the shoulder and elbow through a greater range repeatedly daily may cause fatigue or injury. Only the right turn was analyzed and under normal conditions this requires the right shoulder to flex more than the left shoulder and the left elbow to flex more. However, even though the right side was braced, the left elbow did not show dominance or flex more than the right side (Figure 3). This demonstrates that the affected (simulated amputated) side can change the kinematics of the unaffected (sound) side. Bilateral tasks should be considered when developing design parameters of a transradial prosthesis.

Although some manufacturers (Otto Bock, Dunderstadt, Germany) of prosthetic limbs have developed a wrist rotator, control of these devices may be difficult and the hardware adds weight. The steering wheel turning task is an example showing that pronation and supination of the forearm is important to avoid greater range of motions in the intact joints.

The bracing was an attempt to simulate a transradial prosthesis without wrist or forearm rotation, however, amputees have a decrease in musculature and varied lengths of residual limbs which change the lever arm which was not simulated in this study. Special attention was given to encourage subjects to use only the thumb, pointer and middle finger of the braced arm to hold the steering wheel, but this was not an exact simulation of a prosthetic hand.

Upper limb motions are often more complicated than repetitive lower limb motions such as gait. This makes designing an upper limb prosthesis difficult. Data from this study will be used to develop a kinematic model for a transradial prosthesis. This modeling can be used to test new prosthetic designs and for developing virtual reality training tools to improve the rehabilitation techniques for proper prosthetic use. Future work will examine the transradial prosthesis wearing population as well as the effects on joint torques during unilateral and bilateral tasks.

5 Conclusions

Removing the ability to pronate or supinate the forearm or move the wrist by using a brace requires greater shoulder and elbow flexion as compensation while turning a steering wheel. Lack of movement of the right forearm and wrist can also affect the left arm. Bilateral tasks and compensatory motion should be considered when designing a transradial prosthesis, because requiring the shoulder and elbow joints to exert a greater range of motion often may lead to repetitive motion injuries.

Acknowledgments

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