SOFT ROBOTIC SHOULDER ASSIST DEVICE - TOWARDS PREVENTION OF SHOULDER OVERUSE SYNDROME IN WHEELCHAIR USERS

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BACKGROUND

Shoulder overuse syndrome (SOS) is a fatigue-related condition caused by repetitive motion or excessive practice, common amongst wheelchair users. Diagnostic treatment methods for SOS include physiotherapy sessions, kinesiology tapes and few other measures. Many commercial devices available in the market targeting rehabilitation and recovery of shoulder pathologies are expensive and inaccessible for in-home treatment. A detailed survey of the rehabilitative devices for upper limbs is given in [1]. Although, prognostic measures to avoid SOS in wheelchair users such as taking smoother strides and altering wheel stroke mechanics have been suggested [2], [3], there is a clear lack of assistive devices that augment the shoulder joint muscles during wheelchair propulsion.

Each wheelchair propulsion stroke has been divided into two phases, a rim phase and a recovery phase. The rim phase has been further divided into two different sub phases, pull phase and push phase. The major force contributors include the anterior deltoid, pectoral major, infraspinatus and bicep muscle groups, but the magnitude varies with change in velocity, acceleration, and stroke pattern (Circular, Semicircular, Pumping, Single Looping and Double Looping) employed [4], [5].

The shoulder joint kinetics was extensively studied using inverse dynamic models and it was concluded that a reduction of the overall force required to propel a wheelchair was required to preserve upper limb integrity [6]. After considering the constraints such as isolation of muscle groups and locating the muscle fiber anchor points, the anterior deltoid was having a high workability. The anterior deltoid muscle group plays a significant role during the initial stage of the push sub phase of the wheelchair stroke cycle [5], and provides a peak force of approximately 80N [7]. Hence, the anterior deltoid was selected as the target muscle group and was reaffirmed by our clinical collaborators.
In this paper, a wearable, soft robotic shoulder assist device, utilizing pneumatic artificial muscles (PAMs) to assist the biological muscles during the push phase of the wheelchair stroke cycle is presented. A preliminary evaluation of the assistance provided by this device in propelling a wheelchair forward by means of muscle activity data of the anterior deltoid (ADLT) is provided.

**METHODS**

The soft robotic shoulder assist device utilizes PAM actuators which run along the biceps of the arm, parallel to the anterior deltoid muscle group as shown in Figure 1. These actuators are attached to a shoulder harness on one end and to an elbow brace on the other. Upon inflation with pressurized air, they contract generating an assistive moment about the shoulder, aiding in the wheelchair propulsion. The PAMs were subjected to constant pressure and isometric tests were conducted on a universal testing machine (Instron 5944, Instron Corp., High Wycombe, United Kingdom) to evaluate their performance.

A kinematic study was performed to determine the motion path and the joint angle of the arm with respect to the torso, during the wheelchair stroke cycle. Passive-reflective markers were placed on the arm of a healthy test participant that operates a wheelchair. Image-capturing techniques were used to analyze the motion of the arm during the wheelchair stroke cycle.

The shoulder being a complex joint with numerous degrees of freedom in rotational and translational axes, anchor points were needed to be established such that there is no loss in transmission of the force generated by PAM. Two strategies were considered. One was to have both the PAMs utilized in the device anchored to a single point at the pivot joint behind the neck. The other was to have each of the PAMs anchored to the ends of the collar bone respectively.

These two strategies were evaluated such that suitable assistance could be provided to the shoulder whilst not applying any undesired forces causing the device to slip and not generate pressure points on the human body. One end of the PAM was anchored on a shoulder harness using a leather piece to prevent slippage and the other end attached an elbow brace through flexible cables.

Custom end caps threaded with eyebolts were utilized to connect the cable ends to the PAMs. The elbow brace was fitted with a soft thermoformed padding, attached with cables. Cables were used to transmit the force applied by the PAM normal to the arm to avoid shear forces being generated while the padding was used to distribute the forces over a larger body area.

Through a kinematic study and analysis of the forces developed in the shoulder brace, modifications were made to an off the shelf brace to ensure the movement of the body harness was minimal yet comfortable to the wearer. These include a front strap and a rear neck support that divert the forces onto regions with high stiffness in the body. The mid part of the chest and the back of the neck were identified as suitable regions. Figure 3, shows the distribution of the forces as these act on the device and human body.

A compact control unit including solenoid valves, a power system for the valves, and an electronic microcontroller was mounted under the wheelchair seat. User intent was detected...
using an integrated inertial measurement unit (IMU) located on the elbow brace. The varying shoulder angle was continually monitored by the IMU and the solenoid valves activated early during the push phase, allowing compressed air to pressurize the PAMs and assist with the motion by providing additional moment to the shoulder. Deactivation of the valves occurred at approximately 50% in the stroke cycle allowing to exhaust the air and the PAMs to return to their relaxed state while the remaining stroke cycle is completed unobstructed by the user.

RESULTS

The effective range of motion of the shoulder during the stroke cycle was determined to be -60° to 15° from the top dead center (sign convention taken was negative for counterclockwise direction and positive in clockwise direction). For this range of motion, an initial length and contraction of the PAM were determined to be 27 cm and 4 cm respectively for an average size male.

PAM actuators of various diameters were tested and an optimal diameter of 14mm was determined. Whilst testing PAMs with a diameter of 14 mm and length of 27 mm, the maximum force output at a constant pressure of 207 kPa (30 psi) was determined to be approximately 100 N. This force can be compared to the compressive force generated by the biological ADLT muscle as shown in Figure 2.

To benchmark the device, surface electromyography (sEMG) signals from the right and left anterior deltoid muscles were obtained in successive stages to evaluate performance: a) without the device being worn (Baseline) and, b) with the device being worn and active (Device Active). For each of the test sessions, a participant was tested on an instrumented treadmill set at a constant speed of 0.12 m/s, propelling the wheelchair for three minutes. A rest period of twenty minutes followed every test to relax the muscles. During the Device Active sessions, the PAMs were pressurized at 207 kPa (30 psi) during the push phase.

Figure 4(a) and 4(b) depict the right and left anterior deltoid muscle activity respectively, when operating the wheelchair, averaging 10 consecutive stroke cycles. A reduction in muscle activity is observed from the results when the device is active as compared to the baseline. Further testing with multiple users and other related muscle groups is required for more comprehensive results that would validate the hypothesis of an assistive device that reduces the risks of shoulder overuse syndromes.

Future work will involve optimizing the actuators to match the anatomy variations of different users, mounting the elbow brace and shoulder harness on a monolithic piece of garment to further ease the wear ability, observing the change patterns of force distribution for multiple users, studying the effects of varying arm lengths, propulsion strokes, velocity and increasing the sample size of sEMG data from more muscle groups.

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REFERENCES