Materials and Methods

A total of seven healthy male participants (age: 32 ± 8 years old; height: 181.1 ± 5.3 cm; weight: 89.1 ± 13.3 kg) were recruited for this study. A customized workstation was built to simulate a typical working setup for masonry workers on an unstable work platform. The subjects were asked to lift a cinder block (35 lbs.; 8 X 8 X 16 inches) from the production table at their left side and place it on the simulated wall at their right side. The production table height was set at the subject's hip height. The simulated wall height was set at two different levels—the subject's elbow height and the shoulder height. The subjects repeated the same tasks twice and at two heights of the simulated wall with four different conditions—without wearing an exoskeleton (NoExo), and wearing three passive shoulder exoskeletons (Exo1, Exo2 and Exo3) respectively. Each subject performed a total of 16 trials.

The K-Force plates (KINVENT Biomechanique SAS, Montpellier, France) equipped with electronic force transducers was used to record the subject's ground reaction forces with a sample frequency of 75 Hz while performing the block-laying tasks. To evaluate the subject's stability and balance, three balance-related parameters were calculated using the coordinates of center of pressure (COP) recorded by the force plates: (1) the mean distance (MDIST), (2) the total excursion (EXCUR), and (3) the mean velocity of the movement (VEL). To calculate MDIST, the resultant distance (RD), which is the vector distance from the mean COP location to each point in the antero-posterior (AP) and medio-lateral (ML) directions was first obtained. The mean value of all RD during a recorded movement becomes the MDIST. MDIST represents the average distance from the COP of any given motion during the movement to the mean COP location of the entire movement. The EXCUR represents the total COP travelled distance during the movement. Finally, the VEL is defined as the average COP travelling velocity which is EXCUR divided by the total time of the movement. The MDIST, EXCUR and VEL in both AP and ML directions were also calculated.

Electromyography (EMG) data were collected from six shoulder and upper arm muscles from each participant's dominant side—upper trapezius (UppTrapezius), anterior deltoid (AntDeltoid), medial deltoid (MedDeltoid), posterior deltoid (PostDeltoid), biceps and triceps. The EMG data of the arm muscles were recorded using the Delsys Quattro sensors and the EMG data from the shoulder muscles were recorded using the Delsys Avanti sensors (Delsys Inc., Natick, MA, USA). All the EMG signals were resampled at 2000 Hz. The raw EMG data were filtered by applying a 4th order Butterworth band-pass filter with lower and upper cut-off frequencies of 20 Hz and 450 Hz. After applying the filter, the signal was rectified by taking the absolute value. The rectified EMG signal was then smoothed by the Root Mean Square (RMS) envelope with a 50-millisecond moving window. For each muscle, the peak EMG value across all the dynamic trials was used as a reference EMG value for the EMG normalization. The EMG data of each trial was collected from the neutral starting position to the neutral ending position and then normalized. The mean and peak normalized EMG data were calculated for each trial. The data from replicate trials were averaged for the same conditions.