Flexion-Withdrawal Reflexes in the Upper-Limb Adapt to the Position of the Limb.

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INTRODUCTION
Noxious electrical stimulation of the fingers produces a coordinated reflex response in upper limb muscles that results in the withdrawal of the limb, analogous to removing the hand from touching a hot stove [1, 2]. In general, the upper limb withdrawal is accomplished by a proximal-distal progression of shoulder extension, elbow flexion, and wrist extension [1]. However, exceptions to coordinated withdrawal movement patterns have been observed. For example, some stimulation sites in the lower limb make the leg extend rather than flex [3]. The response of the upper limb has not been studied in the same detail as the lower limb; however, it has been shown that the reflex response can modulate with the phase of movement, as occurs with reaching tasks in the upper limb [4]. The cutaneous afferent feedback (Aδ, C-fiber) responsible for the withdrawal reflex does not make direct connections onto motor neurons in the spinal cord. This suggests that these complex neural circuits would be mutable under different task conditions, operating in the best manner to remove the limb from the painful environment. The purpose of the present experiment was to test the flexibility of the flexion-withdrawal reflex and torque responses by observing the behavior of the limb when it is in different positions. We hypothesized that the flexion-withdrawal response would coordinate to match the limitations placed on the arm due to positioning.

METHODS
Ten healthy adults (28.6 ± 3.9 yrs) participated in the experiments and provided informed consent through Northwestern University. Each subject was tested with the arm in three different positions (Table 1). Noxious electrical stimulation was delivered through ring electrodes placed on the index finger (Digit II). Constant current stimulus trains (20 ms duration) consisting of 10 pulses at a rate of 300 Hz were delivered at random intervals for a total of 8 stimuli in each of the arm positions. The typical stimulus intensity to evoke a painful response was 40—50 mA, and was at least 30—40 X perceptual threshold. Electromyograms (EMGs) were recorded from the brachioradialis (BRD), biceps brachii lateral head (BIC), triceps brachii lateral head (TRI), anterior deltoid (AD), and posterior deltoide (PD) muscles. The subject’s forearm was secured to a 6-DOF load cell (JR-3) with an orthosis and the torso was restrained in a chair.

Table 1. Arm Configurations

<table>
<thead>
<tr>
<th></th>
<th>Elbow Flexion</th>
<th>Shoulder Flexion</th>
<th>Shoulder Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLEX</td>
<td>128.2°</td>
<td>28.4°</td>
<td>80.0°</td>
</tr>
<tr>
<td>MID</td>
<td>87.7°</td>
<td>49.1°</td>
<td>67.2°</td>
</tr>
<tr>
<td>EXT</td>
<td>41.8°</td>
<td>73.9°</td>
<td>78.9°</td>
</tr>
</tbody>
</table>

Reflex responses in the upper-limb muscles were quantified by recording the mean of the rectified EMG for a time window between 60—120 ms for the shoulder muscles and 80—140 ms for the arm muscles (consistent with the onset times of the reflexes), averaged across all 8 trials in each arm position. Resultant endpoint force vectors in the transverse plane were calculated by taking the mean of the endpoint forces for a 20 ms window following force signal onset, defined as the point when the signal exceeded 2 standard deviations above the mean of the force before stimulation. The 20 ms time window was chosen to avoid later, voluntary force changes. Paired t-tests were used to compare EMGs as well as the angle of the vectors and the magnitudes of the vectors in the x- and y-directions.
RESULTS AND DISCUSSION

The results of the current study demonstrated the flexibility the nervous system has in choosing the appropriate motor action following a painful stimulus to the index finger. For example, when the arm was flexed into the chest (FLEX) the response was to pull the arm across the body (Fig.1, Left). Alternatively, when the arm was extended (EXT) in front of the body the reflex response was to withdraw the arm backwards, closer to the midline of the body (Fig.1, Right). There were significant differences in the angle of the resultant vector between FLEX and both MID and EXT positions (both, \(P<0.001\)), and the magnitude of the vector was significantly greater in the lateral direction in the FLEX position (\(P=0.002\) and \(P<0.001\), MID and EXT, respectively). Posture-dependent changes in muscle activation were consistent with the measured endpoint forces. EMG activity in the upper limb muscles during the reflex period was generally greater when the arm was in the flexed position. Specifically, reflex responses in biceps brachii (\(P=0.03\)) and posterior deltoid (\(P=0.03\)) were greater when the arm was flexed (Fig. 2, right). The latencies for the reflex responses were not different between arm positions; however, the latencies were consistently shorter in the posterior deltoid (62.5±2.3 ms) than in either of the elbow flexor muscles (BRD 81.5 ± 4.3 ms, \(P<0.001\); BIC 84.1 ± 3.5 ms, \(P<0.001\)). This is consistent with the progression of shoulder extension followed by elbow extension [1].

CONCLUSIONS

The present study examined posture-dependent changes of the flexion withdrawal reflex in the human arm. The first position, with the arm flexed close to the body, resulted in the subject drawing the arm across the body to remove it from the stimulus. Importantly, even though a potential strategy would be to push the arm in the anterior direction since it is limited in moving in the posterior direction, we observed no extension reflexes in any of the conditions, as is observed under certain conditions in the lower limb [2]. Alternatively, when the arm is furthest from the body, the strategy is to pull the arm back closer to the midline. The differences in withdrawal movements could reflect the flexibility of these reflexes in performing a motor action that can protect the system. Another potential explanation for the results is that the different withdrawal force directions are due to changes in the biomechanics of the limb when altering arm positions. This possibility is currently being explored with upper limb musculoskeletal modeling.

REFERENCES


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