Effect of Wearing a Static Wrist Orthosis on Shoulder Movement During Feeding

Terri L. May-Lisowski, Phyllis M. King

OBJECTIVE. This study compares the effect of wrist immobilization with non-immobilization on shoulder abduction, shoulder flexion, and shoulder rotation during feeding.

METHOD. Twenty right-hand-dominant participants with no upper-extremity dysfunction performed a controlled feeding activity under 2 separate wrist conditions: (1) while wearing a static wrist orthosis and (2) with the wrist not immobilized (free wrist). A Motion Monitor system using small magnetic sensors was used to measure range of motion. Data analysis included paired t-tests to compare the 2 conditions.

RESULTS. Statistically significant results were found for shoulder flexion and shoulder abduction, indicating increased movement at the shoulder while feeding when the wrist was immobilized. No significant difference was found in shoulder internal rotation.

CONCLUSIONS. Wearing a wrist orthosis while feeding may alter normal movement patterns at the shoulder. Future research should examine the effects of wrist splinting on shoulder movement.


Movement in the human body is a complex interaction of joint and muscle activity. The muscles of the upper extremities stabilize joints, contract to produce joint motion, and work in tandem to efficiently move the upper extremity in specific directions. Optimal movement patterns depend on each component’s functioning in a particular way. Coordinated upper-extremity movement patterns enable daily functional activities such as dressing, typing on a keyboard, eating dinner, or walking with an assistive device. The coordinated performance of these activities may be changed if one component of the system is immobilized with an orthosis or splint.

Occupational therapists frequently work with clients who have experienced dysfunction of the upper extremity for which immobilization is recommended. Some upper-extremity disorders that commonly call for immobilization of one or more joints are wrist fractures, de Quervain’s tenosynovitis, carpal tunnel syndrome, and rheumatoid arthritis (Capasso, Testa, Maffuli, Turco, & Piluso, 2002; Feinberg & Brandt, 1981; Gerritsen, Korthals-deBos, Laboyrie de Vet, Scholten, & Bouten, 2006; Lee & Hausman, 2005; Pfeiffer, Nübling, Siebert, & Schädel-Höpfner, 2006). The immobilization of affected joints is intended to allow rest for tissues, alleviate pain from movement, and prevent further injury or irritation.

Pivotal to occupational therapy, and reflected in the treatment provided by occupational therapists, is the importance of everyday activities and people’s functional ability to participate in these activities as independently as possible. Understanding the consequences of the use of orthotics on upper-extremity function will inform occupational therapy practice. In understanding all possible effects of
immobilization, occupational therapists will be able to provide improved treatment and education for patients with upper-extremity conditions.

**Purpose of Study**

This study examined the effect of wrist immobilization on shoulder joint movement during a feeding activity. Previous research on shoulder motion during self-feeding tasks has indicated that the usual pattern of motion includes flexion, abduction, and internal rotation (Safaei-Rad, Shwedyk, Quanbury, & Cooper, 1990). If the wrist is immobilized by a static orthosis, as with some medical conditions, some form of compensatory movement in the proximal joints may be expected during the performance of self-feeding. We compared shoulder motions when participants engaged in a single feeding activity under a free-wrist, non-immobilized condition and under an immobilizing wrist orthosis condition.

**Background**

Immobilization is a common treatment method used to restrict joint motion that could otherwise prolong healing or cause further damage to the joint or surrounding structures. The most restrictive method of immobilization is casting. With casting, the joint and surrounding tissues are constantly immobilized in a rigid, nonyielding plaster or fiberglass cast. Wrist immobilization with a cast may be used when there has been a structural injury, such as a fracture (Pfeiffer et al., 2006). With fractures, complete immobilization of the damaged bone and the surrounding joints allows healing without disturbance to the fracture site. During the initial period of healing, the motion of joints near the fracture site and the associated contraction of muscles attached to the healing bones could prevent the fracture from healing properly (Skirven & Trope, 1994).

Custom splinting with thermoplastic materials offers a less restrictive form of immobilization. Custom splints are common for conditions like carpal tunnel syndrome (Muller et al., 2004). Wrist immobilization with custom thermoplastic splinting may be used when some restricted movement is allowed but restrictions in motion would be beneficial or when an intermittent wearing schedule is indicated. The recommended wearing schedule for thermoplastic splints often includes removal for hygiene, grooming, exercise, or work. The use of custom-fitted splints has been associated with improvement in carpal tunnel syndrome symptoms and in median nerve conduction velocity (Premoselli, Sioli, Grossi, & Cerri, 2006).

Even less restrictive are soft, removable commercial braces, which are often made of fabric or leather with a metal or plastic piece to restrict joint motion. They generally allow some movement and are often used when some support for a joint is necessary to aid in the healing process. Wrist immobilization using soft commercially available braces has been associated with less pain or discomfort for conditions such as rheumatoid arthritis, carpal tunnel syndrome, and de Quervain’s tenosynovitis (Capasso et al., 2002; Michlovitz, 2004; Pagnotta, Baron, & Korner-Bitensky, 1998).

**Impact of Immobilization on the Upper Extremity**

The introduction of a splint is intended to elicit a positive change, such as improved joint stabilization, better functional ability, decreased hand deformity, or reduction of pain or swelling. Negative changes, however, can also result. Emerging research has explored the potential effect of splinting on muscle activity and on the motion of related joints (Bulthaupt, Cipriani, & Thomas, 1999; King, Thomas, & Rice, 2003; Mell, Childress, & Hughes, 2005; Pagnotta et al. 1998).

Some of the early research suggested that movement patterns of the upper extremity change when an orthosis is applied (Carlson & Trombly, 1983; Millender & Nalebuff, 1973; Stern, 1991). Study participants reported changes in their own movement patterns after wrist immobilization. Millender and Nalebuff (1973), in their follow-up study with patients who had undergone wrist fusion, wrote, “The patients uniformly described patterns of substitution, and used the elbow and the shoulder in these patterns” (p. 1033). Other researchers have also received spontaneous feedback from their research participants commenting on their experience of shoulder fatigue during wrist immobilization (Carlson & Trombly, 1983). These researchers speculated that proximal substitution patterns may be a result of wrist immobilization and that this area warrants further research. More recent studies have found that in immobilized conditions, participants demonstrated an increased amount of time to complete tasks and increased muscle activity of forearm and shoulder muscles, used greater arcs of motion, and produced less direct movements (Adams, Grosland, Murphy, & McCullough, 2003; Bulthaupt et al., 1999; King et al., 2003).

Pagnotta et al. (1998) investigated the use of a commercially available wrist splint for people with rheumatoid arthritis. Although wrist pain was significantly decreased when various tasks were performed while wearing the orthosis, the time to complete tasks and performance on the Jebsen Hand Function Test (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969) were significantly slower. Adams et al. (2003) also found slower performance when comparing an immobilized-wrist condition with a free-wrist condition.
Study participants were slower on the Jebsen Hand Function Test and in several routine daily activities and demonstrated an increased range of shoulder abduction when wearing the wrist orthosis.

Bulthaup et al. (1999) examined the effects of various removable commercial wrist braces on upper-extremity muscle activity during everyday tasks. Few differences were found between the splint styles; however, for some object manipulation tasks they found significant increases in muscular activity in several shoulder muscles and in the wrist flexor muscles in the immobilized-wrist condition. Shu and Mirka (2006) also examined forearm muscle activity in participants attempting to perform work tasks using hand tools in free-wrist and immobilized-wrist conditions. They found that commercially available removable splints effectively limited wrist motions yet resulted in increased forearm muscle activity and increased shoulder motions during task performance. These studies contradict the treatment objective of providing rest for the tissues surrounding the immobilized joint.

King et al. (2003) also found that while wearing a wrist splint, healthy participants performed some daily functional tasks more slowly and with a greater range of shoulder motions. The reduced quality of movement continued after a week of continuous splint use.

When the wrist is immobilized, the other joints of the upper extremity may compensate for the lack of movement at the wrist. The forearm and the elbow joints have limited ability to vary in their movement (supination–pronation or extension–flexion). The shoulder, however, is extremely mobile, and movement patterns can vary in many ways to accommodate for limitations in wrist motion. If, because of an immobilized wrist, a different movement pattern does occur, these changes may place more stress on the joints performing the new movement pattern. For a healthy person with a transient condition requiring immobilization, it is unlikely that long-term repercussions will arise from short-term immobilization. However, for people with chronic conditions, such as carpal tunnel syndrome and rheumatoid arthritis, consequences may occur from long-term use of a wrist orthosis and the accompanying altered movement patterns. Accurate measurements of upper-extremity motion and muscle activity during the performance of daily tasks may provide information on the effects of wrist immobilization.

In 1968, Engen and Spencer conducted one of the earliest uses of motion analysis of the upper extremity using mirrors and a 35-mm movie camera. Other types of upper-extremity analysis have included the use of electrogoniometers (Brunfield & Champoux, 1984; Carlson & Trombly, 1983), sonic digitizers (Engin & Chen, 1986), potentiometers (Pronk, 1988), three-dimensional measurement using an Isotrax system (Johnson & Anderson, 1990), electromyography (Bulthaup et al., 1999; Kruger, Kraft, Deitz, Ameis, & Polissar, 1991; Mell, Friedman, Hughes, & Carpenter, 2006; Shu & Mirka, 2006), and electromagnetic motion analysis (King et al., 2003; Mell et al., 2005; Shu & Mirka, 2006).

Most recently, electromagnetic tracking has become an invaluable asset to the study of upper-extremity kinematics. King et al. (2003) used a motion analysis system to quantify the effects of wearing a wrist orthosis on upper-extremity kinematics. They documented significant increases in shoulder motions and in the amount of displacement, or extraneous motions, in some functional tasks in the immobilized condition. Using an electromagnetic tracking system, Mell et al. (2006) found similar significant increases in shoulder elevation in an immobilized wrist during a tabletop task.

We designed this study to add to the understanding of how, during the performance of a basic activity of daily living such as feeding, the proximal shoulder joint may be affected when the wrist is immobilized. We examined the movement pattern differences exhibited under two conditions: fork-to-mouth activity while the wrist was not immobilized and while it was immobilized with a static wrist orthosis. The motions of the upper extremity were quantified using an electromagnetic tracking system.

Method

We examined the movement patterns of the shoulder in 20 participants during a feeding activity under a free-wrist condition and an immobilized-wrist condition. Previous research supports the notion that participants would exhibit compensatory movement during the immobilized condition in shoulder flexion, shoulder abduction, and shoulder internal rotation.

Variables

The two independent variables in this study were the free-wrist condition and the immobilized-wrist condition. The immobilized condition was accomplished by using a static wrist cock-up splint positioned at 30° wrist extension. The dependent variables were the arcs of motion, measured in degrees of shoulder flexion, shoulder abduction, and shoulder internal rotation as represented in continuous kinematic data recorded by the motion monitoring system.

Participants

Twenty participants for this study were recruited from a Midwestern university setting. Participants included 2 men and 18 women older than age 18. As per previous upper-extremity studies (Brunfield & Champoux, 1984; Bulthaup
et al., 1999; Cooper, Shwedty, Quanbury, Miller, & Hildebrand, 1993; Safaei-Rad et al., 1990), the protocol included only right-hand-dominant participants. Criteria for participation included generally good health (as reported by the participant), no history of right upper-extremity injury, normal function of the dominant right upper extremity, and normal range of motion in the upper extremity.

We screened participants for previous upper-extremity injuries via an initial interview. Participants were excluded if they had complicating conditions that may have hindered normal hand function or caused limitation in normal range of motion of the dominant upper extremity. Participants were also excluded if they had any conditions that were contraindicated in using magnetic equipment (e.g., seizure disorders, metal devices or implants, pacemakers). We used small brownie cubes during the feeding activity, and participants were excluded if they reported allergies to chocolate or nut products.

**Procedure**

To minimize the possibility of researcher error, we followed a standard procedure for each participant. On entering the laboratory, each participant was briefed on the study protocol and signed a consent form. Each participant’s hand was then measured for the correct commercially available static wrist brace according to the manufacturer’s instructions for proper sizing.

All participants were seated in a standardized position with feet flat on the floor and with the lower extremities positioned so that the ankle, knee, and hip joints were at 90°. The upper body was positioned so the trunk was 4 to 6 in. from the edge of the table. The upper extremity was positioned so the elbow was flexed to 90° and the forearm was touching the top of the table. The collection table was arranged the same for all participants. The starting position for the hand was marked on the top of the table. The nearest edge of the small plate containing the brownie pieces was positioned 5 in. from the edge of the table, centered in front of the participant.

Magnetic sensors were placed at the proper locations on the participant. To collect as accurate and natural movements as possible, participants used (plastic) utensils and real food for the activity. Previous studies have used muffins, yogurt, and juice during feeding tasks (Cooper et al., 1993). In this study, the participants used a fork to pick up small, uniformly sized brownie pieces.

Before data collection, all participants were instructed on the procedures using standard verbal directions. Participants were instructed to keep their backs against the chair and not to lean forward during the data collection. They used a standard thumb web-space grasp, using the thumb, index finger, and middle finger of the right hand to hold the fork throughout the data collection period. One cycle of the feeding activity included beginning with the fork in the hand at the starting position on the table; piercing one piece of brownie with the fork; bringing the brownie piece to the mouth; and returning to the start position, still holding the fork. After a demonstration trial, participants each completed five cycles of feeding in either the free or the immobilized condition. The procedure was then repeated for the other wrist condition. The participants were instructed to perform the fork-to-mouth task at a normal pace until all the brownie pieces were gone. The participants’ first condition (free wrist or immobilized) was altered in an A–B–B–A pattern to control for ordering effects. At the end of the study, 10 participants had started with the free-wrist condition, and 10 with the immobilized-wrist condition.

**Instrumentation**

We used the Motion Monitor system to collect joint-angle data via seven magnetic sensors. A sensor was attached to each of the following areas: head, back of the neck, back in the lumbar region, spine of the scapula, upper arm, extensor side of the forearm (staying free of the orthosis area so the sensor would not be removed during the entire collection session), and third metacarpal on the dorsum of the hand. The sensors attached to the head and lumbar region were secured using a Vel-foam band; the other sensors were secured using medical tape directly to the skin. Before each data collection session, the system was reset by activating the sensors and establishing the x- and y-axes by placing a sensor at two specific points along each axis, spaced 10 in. apart. The Motion Monitor collected data at a rate of 100 Hz and used a Butterworth smoothing function. The data capture period was set at 10 s.

The Motion Monitor system uses electromagnetic tracking sensors called “flock of birds.” The device provided continuous measurement of motion in 6° of freedom. Although the system collected data in the form of radians (units of angular measurement), they were converted to the more familiar angular unit of degrees for analysis of joint range of motion. Calibration of the system included defining the arc of motion. Shoulder flexion and abduction were defined as beginning at 0 when the arm was alongside the body. Shoulder internal rotation was defined as 0 with the forearm at neutral rotation relative to the humerus and the trunk. The accuracy of electromagnetic tracking has been studied and found to have fewer than 2% errors. The optimal range for the transmission of data from the sensors on the participant to the transmitter was established as 22.5 cm to 64.0 cm. Within this range, there was an error of 0.5 mm (Milne, Chess, Johnson, & King, 1996). Milne et al. (1996) exam-
ined the effects of different metal objects within the transmission field on the sensitivity of the system and found that only mild steel produced significant interference. Although orthopedic surgical alloys were not found to produce interference, potential participants were eliminated if they reported any metal implants. Each participant was asked to remove all metal from the collection area, including rings, watches, belts, necklaces, and bracelets.

In addition to eliminating metal from the participants’ personal and testing space, it was necessary to modify the wrist orthoses to remove metal stays. As manufactured, the wrist orthosis contained a metal support on the volar surface of the splint. To eliminate any possibility of interference caused by the metal support, an alternative support was fabricated using thermoplastic splinting material. Two layers of splinting material were molded to reproduce the same 30° angle as the original metal support. Two layers were used to compensate for the flexibility of the thermoplastic material and to make the orthosis more rigid. Mell et al. (2005) used similar modifications in a study in which they replaced the metal support with plastic.

Each session was videotaped to record the actual movement series. The videotape allowed synchronization with the kinematic data of the Motion Monitor system and the behavioral coding necessary to establish the completion of each event.

Data Analysis
To analyze the data, we completed behavioral coding using the video recording of each trial collection. Event markers were placed to indicate the frames at which three events occurred: movement beginning, stab ending, and insertion ending. Two phases were indicated. The first phase started with the beginning of movement from the start position (movement beginning) and ended when the fork was no longer being inserted into the brownie (stab ending). The second phase began with the same frame as the stab ending and was completed when the brownie was no longer being inserted into the mouth (insert stop). After the event markers were designated on the Motion Monitor system, the data were exported into a spreadsheet. Once the data were exported, we designed a macro program to identify the point of maximum degree of movement for each of the dependent variables: shoulder flexion, shoulder abduction, and shoulder internal rotation. The maximum degree of movement was taken from either phase; usually, but not always, the maximum was found in the second phase. The mean maximum degree of movement for each participant was calculated. These means allowed comparison of the independent variables (free-wrist and immobilized-wrist conditions) using paired samples t tests. The effect size, indicating the degree of the relationship between the independent and the dependent variables, is represented by Cohen’s d (Rosnow & Rosenthal, 2003) and is determined by dividing the t value by the square root of the degrees of freedom. Effect sizes using Cohen’s d were operationally defined by Cohen (1992) as small (d = .2), medium (d = .5), and large (d = .8). Cohen (1992) stated that a medium effect size represented an effect that was likely to be obvious to the careful observer.

Because of the use of behavioral coding, the opportunity for coding inaccuracies resulting from human error is exposed. It was necessary to provide interrater reliability measures to ensure coding accuracies. To accomplish this, one of the researchers coded the behavioral data and set event markers using samples from each participant. Using a random numbers table, a single trial was selected for each condition for each participant. The second coder received instructions regarding what distinguished each event. After the initial instruction, no contact was made with the second coder until all samples had been completed.

The behavioral data were gathered from video, as previously discussed. The video collection occurred at 30 frames per second. Because the Motion Monitor collected kinematic data three times more quickly (100 Hz), allowances were made for some discrepancies. To allow for these differences, percentage agreement was calculated using frame blocks (Table 1). The two coders agreed within 0.10 s (87.5%) over all the event markers. There was one outlier for which the coders indicated the stop of a stab with a difference of 74 frames. This is a substantial time difference (0.74 s). In reviewing this particular trial, we found that there was an angle change during the stab process. One coder indicated the time of the angle change to be the end of the stab.

Results
Initially, we intended to collect six trials under each condition. If all trials had been collected, 120 trials for each condition would have been available for analysis. We instead collected 117 free-wrist trials and 115 immobilized-wrist trials. In the free-wrist condition, one participant had 5 trials and one had 4 trials. In the immobilized-wrist condition, five participants had 5 trials recorded. The noncollected trials were a result of our not beginning the recording process by activating the hand-held event marker (3 trials) or of the participant not wanting to eat more brownie (5 trials).

In using the behavioral coding, we found that some trials warranted being eliminated from analysis. The reasons for eliminating trials included the participant starting from a position other than that indicated on the placemat (1 trial), the participant changing the grip of the fork after starting
Table 1. Interrater Reliability of Behavioral Coding

<table>
<thead>
<tr>
<th>Agreement within 0–10 frames (0.00–0.10 s)</th>
<th>Movement</th>
<th>Begin</th>
<th>Stab Stop</th>
<th>Insert Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>87.5</td>
<td>92.5</td>
<td>82.5</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>35</td>
<td>37</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Agreement within 11–20 frames (0.11–0.20 s)</td>
<td>%</td>
<td>10</td>
<td>5</td>
<td>12.5</td>
</tr>
<tr>
<td>n</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Agreement within 21–30 frames (0.21–0.30 s)</td>
<td>%</td>
<td>2.5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>n</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Agreement within 71–80 frames (0.71–0.80 s)</td>
<td>%</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td>n</td>
<td>—</td>
<td>2</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Total number of trials coded</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

Note. Interrater reliability is based on percentage of agreement for coding the event for each time category.

Discussion

During feeding, the splinted condition required a significant increase in shoulder flexion and shoulder abduction but not in shoulder internal rotation. These increases in shoulder motion were not evident in the nonsplinted condition.

Interestingly, the maximum degree of motion for shoulder flexion and shoulder abduction was experienced most often in Phase 2 of the task (stab to insert, 77% and 74%, respectively). However, for shoulder internal rotation the maximum degree of movement only occurred 24% of the time during Phase 2.

On the basis of this study’s findings, it can be suggested that the movement patterns of the shoulder, when performing a functional activity, may change when a static wrist orthosis is introduced. This suggestion is consistent with other current research suggesting that when the wrist is immobilized, people may use compensatory shoulder motions (Mell et al., 2005).

This study looked at healthy participants wearing a wrist orthosis for the duration of the data collection period during a single feeding task. Because of these limitations, the results of this study cannot be generalized to patients with upper-extremity joint disorders. However, the results of this study are important to occupational therapy at a clinical level, laying the groundwork for a better understanding of the treatment programs for relatively common problems that include wrist immobilization. Often, a wrist orthosis may be provided for, or recommended to, the patient without fully

Table 2. Means and Standard Deviations of Maximum Degrees of Shoulder Motions for All Participants and All Trials for Free-Wrist and Immobilized-Wrist Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Flexion</th>
<th>Abduction</th>
<th>Internal Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free wrist</td>
<td>58.058 ± 12.402</td>
<td>46.567 ± 12.001</td>
<td>−6.892 ± 15.014</td>
</tr>
<tr>
<td>Immobilized wrist</td>
<td>66.455 ± 15.427</td>
<td>58.253 ± 19.261</td>
<td>−6.918 ± 16.517</td>
</tr>
</tbody>
</table>

Note. n = 112, free-wrist condition; n = 109, immobilized-wrist condition. Results are reported in degrees of motion.

*aNegative means for shoulder rotation indicate that the mean maximum motion for internal rotation was actually slight external rotation.

Table 3. Paired Differences for Shoulder Motions

<table>
<thead>
<tr>
<th>Shoulder Motion</th>
<th>Mean Differencea</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>p (2-tailed)</th>
<th>d = t/df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder flexion</td>
<td>−7.579</td>
<td>8.972</td>
<td>−3.778</td>
<td>19</td>
<td>0.001*</td>
<td>.867</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>−10.919</td>
<td>14.473</td>
<td>−3.374</td>
<td>19</td>
<td>0.003*</td>
<td>.774</td>
</tr>
<tr>
<td>Shoulder internal rotation</td>
<td>−0.747</td>
<td>4.587</td>
<td>−0.728</td>
<td>19</td>
<td>0.475</td>
<td>.167</td>
</tr>
</tbody>
</table>

Note. N = 20.
aCalculated from the means for each wrist condition on each independent variable for each participant.

* p < .01.
assessing the complete picture or explaining the possible consequences associated with the application of the orthosis. As clinicians, occupational therapists must view each patient as an individual, realizing that individual response to common interventions will depend on many factors, possibly including multijoint involvement.

Future research should include populations affected by upper-extremity joint disorders such as carpal tunnel syndrome or rheumatoid arthritis. Additional research also needs to address the phenomenon of time. This study does not account for possible learned adaptations that may be exhibited after use of a wrist orthosis for any length of time. King et al. (2003) addressed this phenomenon and found evidence to suggest that the immediate changes in movement may be modified by time. As the individual becomes accustomed to wearing the orthosis, he or she may resume more normal movement patterns.

Future studies should also address the wide variance of movement and compensatory movement patterns that people exhibit. Current studies illustrate that immobilization at the wrist level may produce compensatory movements, increasing physical movement at the shoulder and producing an altered quality of motion in the upper extremity (Adams et al., 2003; King et al., 2003, Shu & Mirka, 2006).

References


