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The Relationship of Muscular Peak Changes with Accuracy in an Over-arm Throwing Task

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Summary: Many studies regarding throwing tasks have focused on spatial and temporal characteristics of individual muscles. However, the special relationship between muscles is not entirely clear when it comes to describing human skilled movement. The purpose of the present study was to establish the relationship between accuracy in a throwing task (performance) and electromyograms (EMGs) as a measurement of coordination ability in an over-arm throwing task. We recorded surface EMGs for 17 muscles from the upper limb, trunk, and lower limb during throwing task. The task was to throw to a target, and throwing performance was assessed by an accuracy score. This was conducted to examine the relationship between performance and the peak changes in each EMG. The results showed that the activity peaks of the biceps brachii, extensor digitorum, and right rectus femoris were negatively correlated with performance. Regarding inter-peak periods, the difference in peak latencies between the biceps brachii and the rectus abdominis was correlated with performance, as was the difference between the flexor carpi radialis and the biceps brachii. These results show the ability of muscles to coordinate in an over-arm throwing task.
Key words: over-arm throw, muscle, electromyograms

INTRODUCTION

A number of studies have been made concerning ball throw movements or tasks, because the throwing movement is a key motion in many sports activities (Debicki et al, 2003, Hore and Sherr, 2005, van den Tillaar and Ettema, 2006, Watt et al, 2004, Werner et al, 2007). In a ball throwing movement, it is generally considered that the successive proximal-to-distal sequence of muscle activities is very important for the generation of ball speed (Gray et al, 2006, Hong et al, 2001). This successive sequence has been investigated in many sports activities, including not only baseball pitching (Feltner, 1989, Gross and Grill, 1982, Hirashima et al, 2002) but also other types of throws (Bartlett et al, 1996, Elliot et al, 1989, Wagner et al, 2008). Hirashima et al (2002) have shown that sequential muscle activity is very important for generation of high force and energy in the trunk.

On the other hand, Chowdhary and Challis (2001) have asserted that a proximal to distal sequence of muscle activations is seen in many of the simulated throws, but not all, and that under certain conditions, moment reversal produces a longer throw and greater projectile energy, while the deactivation of the muscles is what results in increased projectile energy. Furthermore, Hong et al (2001) investigated the kinematics and kinetics of the hips, upper trunk, humerus and forearm plus hand of both upper limbs, by a three-dimensional, six-segment model, and indicated that the temporal onset of muscular torques was not in a strictly successive proximal-to-distal sequence. This indicates that the successive proximal-to-distal sequence of muscle activities or segmental sequences is not always associated with the generation of maximal projectile kinetic energy.

In a ball throwing movement, its evaluation as a sports performance is generally based on ball-speed and throwing accuracy. Although both of these factors are required for a general throwing task in a sports exercise, it is difficult to satisfy each of the two requirements simultaneously. Because ball speed in a certain range is inversely related to throwing accuracy (Gross and Gill, 1982), this relationship becomes an important facet of ball throwing technique.

Van den Tillaar and Ettema (2003) showed that, when given instructions that emphasized accuracy, the velocity of an average person's throw was only approximately 85% of the maximal velocity. On the other hand, expert team-handball players did not show this typical trade-off between speed and accuracy in over-arm throwing tasks.

In this manner, the skill of ball throwing is characterized by a combination of speed, accuracy and other features. However, it is necessary to examine more than simply the relationship between speed and accuracy, but also the contributions of individual factors, in order to reveal the skill behind ball throws. In general, the aspects contributing to ball speed have been widely investigated. For example, Hirashima et al (2006) investigated throwing of a ball at a target at different speeds and found that the fingertip speed at ball release was mainly produced by trunk leftward rotation, shoulder internal rotation, elbow extension and wrist flexion for all speeds. Jegede et al (2005) have reported that, although variability in the timing of ball release can affect ball speed, this variability is only a major factor in unskilled throwers. In contrast, when skilled throwers throw fast, the variability in ball speed is due to variability in arm speed.

When compared with studies on ball speed or angle velocity, studies concerning throwing accuracy have not been adequately addressed. In modeling sports activities, the process of transmission of force and energy is thought to involve successive sequences of muscle activities or segmental sequences, that generates a "whip-like movement" (Sanders, 1995, Shan and Westerhoff, 2005). Therefore, sequential changes from proximal to distal proportions have not been sufficiently examined with respect to throwing accuracy.

Many studies have analyzed ball throws through the use of electromyograms (EMGs). EMGs show not only the changes in energetic muscle activities, but also yield information about nerve-muscle systems. During human movement, each muscle generally shows a temporary peak of EMG potential in dynamic control, exclusive of lasting and isometric muscle activity. A relationship of the inter-peaks (peak-synergy) is considered as showing the ability for muscular coordination. However, how the peaks of muscle activities in upper limb, trunk and lower limbs are correlated with accuracy in performance of ball throws is unclear. This is especially true for the relationship between throwing performance and the activities of trunk and lower limb muscles, which play a role in postural control, and which are considered to guarantee throwing accuracy.

Overall, if the peaks of EMGs are examined in conjunction with accuracy of a ball throwing performance, this could be expected to reveal the physiological mechanism in sequential activity and recruitment mode of muscles that give rise to skills in throwing movements. The purpose of this study is therefore to investigate the relationship between the peak-synergy of EMGs measured in upper limbs, trunk and lower limbs as well as the recruitment mode of muscles in comparison to throwing accuracy.

METHODS

Subjects

Fourteen healthy right-handed male subjects (mean age 22.8 ± 4.2 yr; range 18-35) participated in the study, after receiving an explanation of the purpose and procedure of the experiment. No subject had participated in sports that included over-arm throwing and none had been highly trained.

Experimental conditions

Fig. 1 shows the EMGs measurements and the block diagram for this experiment. The subjects

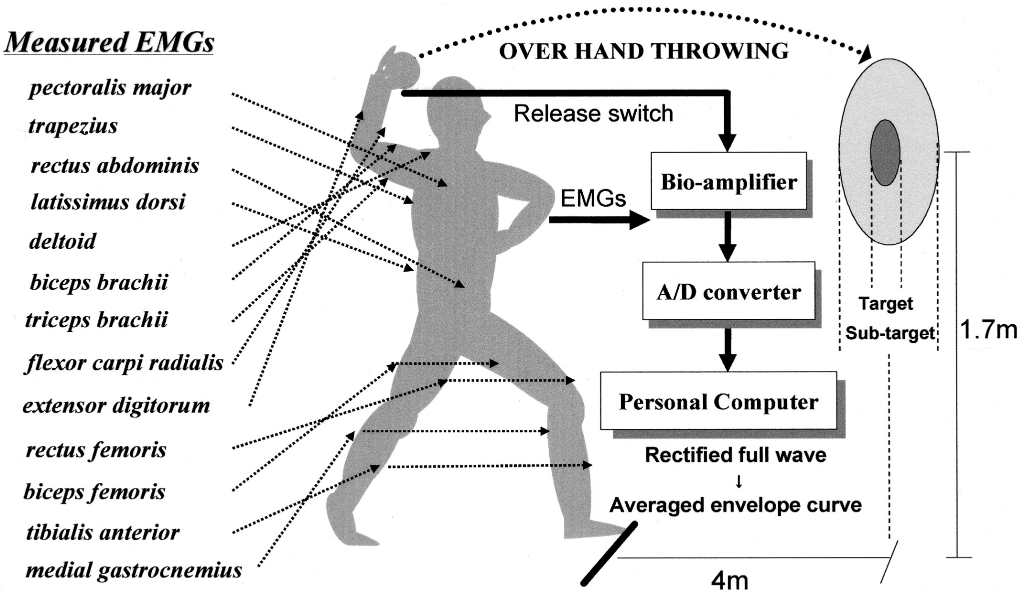

Fig.1 Measurements of EMGs and a block diagram for the experiment

Seventeen EMGs were measured from upper limb, trunk and both right and lower limbs. Subjects threw a ball several times before the experiment to confirm their ability to throw smoothly. Experimenters informed the subjects of the performance measurement (point-score) during the tasks.

were instructed to throw a tennis ball, using their right hand, as accurately as possible towards a target. The throwing tasks were accompanied with a one-step pre-motion of the left lower limb and were executed with free grasping and speed. Fifty trials were performed, with inter-trial intervals of about 10 seconds.

The main target on the wall was a 30cm diameter circle with a sub-target of a 50cm circle around the main target. The target was placed 4m away from a marker line and the center of the target was placed 1.7m above the floor.

EMG recording conditions

The surface EMGs of 17 muscles were recorded from the trunk on the right side and upper limb (pectoralis major, trapezius, latissimus dorsi, rectus abdominis, deltoid, biceps brachii, triceps brachii, flexor carpi radialis, and extensor digitorum) and both the left and right lower limbs (rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius). The EMGs were recorded by bipolar Ag-AgCl disc surface electrodes or disposable electrodes. Inter-electrodes were 3cm apart. Before the electrodes were attached, the surface of the skin was treated with ethanol, and the impedance was maintained below 10kOhm. All recordings were digitized at 1,000Hz and band pass filtered from 30 to 200 Hz. All EMG amplitude values were stored on a personal computer and analyzed off-line using analysis software.

Data Analysis

As an estimation of accuracy performance during the throwing task, the frequency with which the ball hit the target or sub-target was visually recorded. The estimations of scores were divided into three categories. If the subject threw a ball within the limits of target, he gained two points and if the ball went beyond the limits of the target but within the limits of the sub-target, this scored one point. If the ball missed both the main and the sub-target, no points were scored. Thus, if the ball hit the target in center perfectly every time, a maximum score of 100 points could be gained.

The raw EMG signals of each muscle were full wave rectified, and the EMG envelope curves were analyzed by averaging. The trigger pulses were electrical signals generated by a release switch attached to fingers of the subject. The analysis time for the EMG envelope curve was from 4sec before to 1sec after ball release. The peak latencies and peak amplitudes of the EMG envelope curves were measured by personal computer.

Statistical analysis

Spearman's rank correlations were performed to determine significant correlations between the EMGs parameters and performance scores ($p < .05$).

RESULTS

Performance

The performance scores ranged from 41points to 77points with an average of 63.2 and standard deviation of 9.82.

EMG envelope curves

Fig. 2 shows the grand average of EMG envelope curves obtained for this experiment. The EMGs had two characteristics in their waveforms. First, the sequential muscle activities from the lower limb to the trunk and upper limb were observed at the onset time of the EMG peak. Secondly, it was noted that the trapezius, deltoid, biceps brachii, and right tibialis anterior each had two EMG peaks. Therefore, the former peak was designated peak "a", and the latter peak "b". Since trapezius "a", deltoid "a", and biceps brachii "a" showed the movement of the shoulder joint, these peaks could be taken as representing the take-back motion. The right tibialis anterior "a" peak showed a movement of the lower limb that effected a posture control.

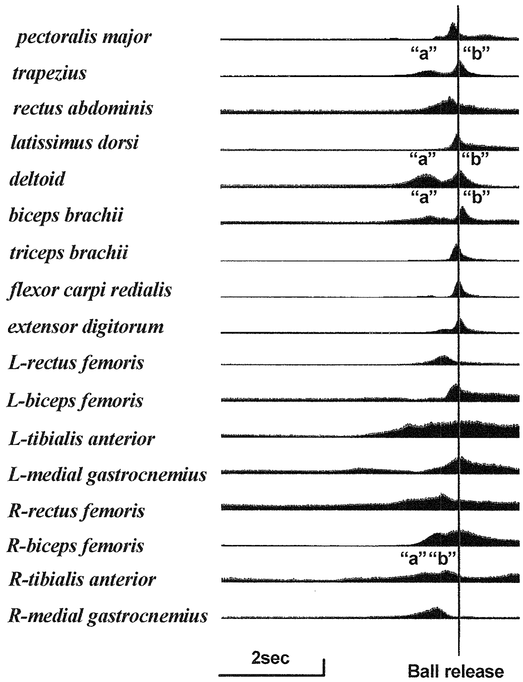

Fig.2 Grand-averaged envelope curves of EMGs

EMGs were full wave rectified and averaged from 50 trials for each subject. The scales of EMG amplitudes are normalized by peak amplitudes of each muscle. The trapezius, deltoid, biceps brachii and right tibialis anterior muscles each had two peaks. Designated as "a" and "b", respectively.

Correlations of performance with peak latencies and amplitudes of EMGs.

To investigate motor control during a throwing task that required accuracy, we

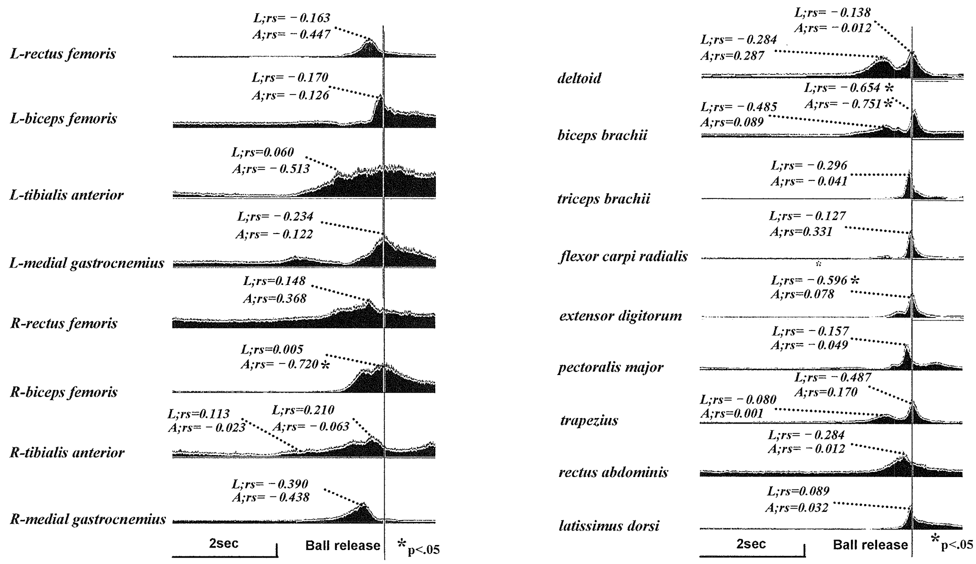

Fig.3 Correlation coefficients between EMG peaks and performance.

"L-" and "R-" on muscles indicate left and right lower limbs, respectively. The correlation coefficients of the performance of ball throwing accuracy with both peaks (L:) and (R:) were obtained.

examined the relationship between all peaks and each subject's performance. Fig.3 shows the correlation of peak latencies and amplitudes of the lower limbs, trunk and upper limbs with performance, respectively. There was a significant correlation between the performance and the latency of biceps brachii peak "b" (rs=-0.654, $p<.05$) and extensor digitorum (rs=-0.596, $p<.05$).

With regard to amplitudes, significant correlations were observed between performance and the right biceps femoris (rs=-0.720, $P<.05$) and biceps brachii peak "b" (rs=-0.751, $P<.05$). In general, correlations between performance and antagonist muscles in the upper limbs in both peak latency and amplitude were characteristic findings.

Relationship between performance and inter-peak

The correlations of performance with the difference between peak latencies, referred to as the "inter-peak", were analyzed to investigate the motor control of throwing at a higher level. Fig.4 shows a significant correlation of performance with the difference between biceps brachii peak "a" and rectus abdominis (rs=0.548, $p<.05$) as well as between the flexor carpi radialis and biceps brachii peak "a" (rs=0.584, $p<.05$). The other inter-peaks were not significantly correlated with performance. Therefore, it is confirmed that the biceps brachii peak "a", which is associated with the onset of flexor arm movement, is important for accurate throwing.

DISCUSSION

The purpose of the present study was to reveal characteristics of throwing tasks that required accuracy, in terms of the relationship between performance and observed peak potentials of EMGs. As a background, there is a principle that muscle sequential recruitment sustains joint movement and, in human movement, muscle activity generally shows a specific sequential change (Bartllet et al, 1996, Cordo et al, 1993, Hirashima et al, 2002, Klein, 2006). Sanders et al (1995) have reported the wave characteristics of butterfly swimming muscle movement, while Shan and Westerhoff (1995) have reported on the full-body kinematic characteristics of the maximal instep soccer kick, with special reference to "whip-like movement" generated by sequential muscle movements.

In a throwing movement, it has been observed that the particular muscle activities sequentially delay from lower limbs to trunk and upper limb. For example, in a throwing task that requires ball speed, muscle activities were sequential from the trunk to the upper limb (Hirashima, 2002, Putnam, 1993). On the other hand, in a throwing task that is related to accuracy, it should be considered that postural control conducts the muscles of the trunk and lower limbs and the changes of joint angle. Therefore, it seems quite probable that muscle activities with concerned with both ball speed and accuracy are also associated with sequential changes.

In this study, to assess throwing accuracy in terms of EMG measurements, we conducted the analysis of sequential EMGs peaks for each muscle. In accordance with a previous study (Hirashima, 2002), we examined the peak latencies of EMGs of the lower limbs, the trunk and the upper limb. Furthermore, we qualified the throwing accuracy and examined the correlation between its performance and EMG peaks. With regard to lower limb muscles, a significant negative correlation between the performance and peak amplitude of right biceps femoris was found. This can be considered to show that the relaxation or the inhibition of right biceps femoris as an antagonist activity is related with smooth movement of the trunk. Thus, these findings indicate that the activities of the lower limb affect performance, such that the postural control conducted by lower limb activity affects the performance, before ball release, in a throwing movement that requires accuracy.

Regarding the trunk muscles, there appeared to be no difference between performance and any peak. However, in the upper limb muscles, there were significant negative correlations between performance and peak latency of the extensor digitorum and biceps brachii peak "b". These findings suggest that, in a throwing task requiring accuracy, the earlier these two peaks occur, the higher the performance will be. Additionally, in biceps brachii peak "b", there was a significant negative correlation between performance and the peak amplitude. In a throwing movement, because the extension of the elbow is the movement that causes release of the ball, the triceps brachii is consequently the agonist muscle. Therefore, inhibition of biceps brachii activity as an antagonist maintains a smooth extension of the elbow. It can be shown that the antagonist muscle of the upper limb supports the performance in determining the level of throwing accuracy. Thus, in a throwing task, a factor to be considered with regards to performance is not only the sequential activity of individual muscles, but also the inhibitory effects of antagonist muscles in both upper and lower limbs.

The “whip-like” movement has been defined as a phenomenon in which dynamic energy is conveyed from the central body to a peripheral limb (Sanders et al, 1995, Shan G and Westerhoff, 2005). As throwing movements are performed with the whole body, the whip effect occurs from the lower limbs to the trunk and to the upper limb sequentially. These movements were studied in terms of the relationships among inter-segments. However, it is shown that the peak of each muscle does not always coincide with the creation of a specific movement such as a whip effect. In other words, the characteristics of a throwing movement that requires accuracy can be clarified by investigating the changes in joint angle and in the recruitment mode of muscles; that is, changes that occur at the onset of a muscular peak.

As a result, there were significant correlations between the performance and two peak differences. The difference between the peak of the flexor carpi radialis and biceps brachii peak "a" before ball release was significantly correlated with the performance. It is considered that the delay time between the two EMGs peaks was not linked automatically, and included a factor that affected performance. Furthermore, the difference between the peak of biceps brachii "a" and the rectus abdominis was negatively correlated with performance.

In summary, the longer the inter-peak is the higher will be the performance. This finding suggests the possibility that the interval between these two muscles affects the accuracy of a throwing movement. Gray et al (2006) investigated the mechanisms of coordination that enable skilled recreational baseball players to make fast over-arm throws with their skilled arm and compared these to their unskilled arm. They indicated that some of segmental differences of rotation velocity in arm kinematics occurred because of differences between the skilled and unskilled arms in their ability to control interaction torques. In this manner, the combinations between segments or muscles are different and depend on the goal, whether it is speed or accuracy.

In the present study, it is thought that the findings about the peak-synergy of the upper arm and the trunk, and the upper arm and the forearm, are essentially associated with performance in throwing accuracy. Therefore, higher performance is shown if the onset of arm movement is not close to the trunk movement; that is, when the interval between the sequences of trunk twitching and take-back of forearm is long or desynchronous. As confirmed in this study, the correlations of the performance with peak amplitude, peak latency, and peak synergy were focused on the biceps brachii and the result obtained concerned a flexion and extension of the carpus. Hirashima et al (2002), using other means of analysis, have reported that the forearm and upper arm affects throwing movements that require accuracy. The results of relationships between the performance and EMG parameters of the upper limb are considered to show a characteristic of throwing movements requiring accuracy, namely that the antagonist muscles are important for performance in these throwing tasks. In conclusion, the relationship between performance and 'peak synergy' can demonstrate the importance of muscular coordination in a throwing movement.

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