J. Human Ergol., **33**: 45-53, 2004

ANALYSIS OF "TENO-UCHI" MANEUVER IN RELEASING JAPANESE-STYLE BOWS BASED ON MUSCLE ACTIVITIES AND FORCES ACTING ON THE BOW

Satoshi Hosoya[1*], Keigo Ohyama Byun[2], and Morihiko Okada[2]

[1] *Department of KANSEI Engineering, Faculty of Textile Science and Technology, Shinshu University, 3-15-1 Tokida, Ueda, Nagano 386-8567, Japan /*Email: hosoya@shinshu-u.ac.jp*
[2] *Institute of Health and Sport Sciences, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba 305-8574, Japan*

Since a Japanese-style bow has a very complicated shape and structure, an archer has to apply the "Teno-uchi" maneuver including horizontally twisting torque, or "Nejiri", and sagittally down-pushing torque, or "Uwa-oshi", to the restoring bow in order to hit the target. The purpose of this study was to investigate the biomechanical relationship between the muscular activities of the left forearm and the operation of "Teno-uchi" maneuver. Surface EMG of left forearm muscles and the two kinds of torque acting on the bow around the time of release were recorded in 10 experienced subjects during arrow shooting. The "Biku", an involuntary resignation from release happening in the shooting, was also examined. Close analyses of the results revealed that activation of the extensor carpi ulnaris and extensor digitorum muscles together with inhibition of the flexor carpi ulnaris muscle brought about "Nejiri", while activation of the extensor carpi ulnaris as well as flexor carpi ulnaris muscles and inhibition of the extensor carpi redialis longus and extensor digitorum muscles gave rise to "Uwa-oshi", thus causing activities of trade-off nature in the extensor digitorum and flexor carpi ulnaris muscles for the "Nejiri" and "Uwa-oshi. The trade-off activities were presumably actualized through time-sharing coordination between the muscles.

Key Words: Japanese-style bow; release; "Teno-uchi" maneuver; EMG; torque

INTRODUCTION

It is not too much to say that any regional population in the world has had some kind of bow as a hunting tool or weapon. A Japanese-style bow is internationally recognized as one of the representative long bows, as its total length reaches 2.21 m. An archer shooting an arrow with a Japanese-style bow acts in a relatively leisurely manner before release, and seems to be at rest in appearance while taking aim at the target. Thus, many people have a static image of Japanese archery. However, it takes only about 20～30 msec from the time when an archer releases the hold of a bowstring to the time when an arrow fit to the bowstring is separated from it. Hereinafter, this period will be referred to as "restoring time". In effect, an arrow-shooting phenomenon ends in an instant; it is very dynamic in contrast with such a static image of archery.

There are numerous sports using some kinds of tool. However, those sports like archery are rare in which the load on a player increases with the advance of the player's motion. When shooting an arrow, an archer has to actively concentrate exertion on a bow against a gradually increasing load from it. In addition, a Japanese-style bow has some structural characteristics that contrast with a Western-style one; the grip is positioned toward the lower end, not in the center, of the total length of the bow, and an arrow is fit to the bowstring on the right side of the bow. If a person simply draws a

Received for publication April 30, 2002

bow and shoots an arrow, the arrow should fly wide of the upper right side of the target mark. Therefore, in order to hit the mark by correcting such simple motions, when shooting an arrow, an archer has to apply two kinds of torque to the bow through the left hand gripping it, i.e. torque about the major axis of a bow ("Nejiri" torque) to twist the bow horizontally and torque about an axis perpendicular to the major axis medio-laterally ("Uwa-oshi" torque) to bring the bow down forward.

Thus, an archer is required to prepare for such torque to be applied to a bow in a very short restoring time of 20 to 30 ms, while the load on the drawing arm is gradually increasing. Instruction books on the Japanese-style archery attach the most importance to the actions of applying "Nejiri" and "Uwa-oshi" torque to a bow with the left hand, calling the combined action the "Teno-uchi" maneuver. This is an example of adaptation to overcome constraints in a traditional tool by developing complex motor skills.

To date, activities of the upper limb and back muscles from the start to the completion of shooting a Japanese-style bow have been examined in numerous studies (e.g., Ono, 1969). However, to analyze the art of hitting the target, or "Teno-uchi" maneuver, it is indispensable to investigate the activities of forearm muscles for a period from immediately before to after release because the muscle activities responsible for the maneuver are likely to occur during this period. In this study, the "Teno-uchi" maneuver as motor adaptation to implemental constraint was analyzed by examining the muscular activities of the left forearm and the torque acting on the bow for the period mentioned above.

METHODS

Subjects, bows, and trials of arrow shooting

Ten subjects, all were healthy men, were chosen out of those who took lessons in the art of the sect of INSAI, the school of HEKI, for this experiment. They were explained on the purpose of the study and submitted the informed consents. In mean ± SD, the age, height and weight of the subjects were 22.5 ± 7.9 years, 174.3 ± 5.5 cm and 64.5 ± 4.6 kg, respectively; the number of years they had received training in the art was 7.5 ± 6.3 years; their mean hit rate for several weeks before the experiment was 71.8 ± 7.8 %; and the strength of the bows they usually operated was 209.1 ± 20.0 N/m. Two bows were used in our experiment; one usually operated by each subject in practice and the other made of carbon fiber with a strength of 183 N/m. With sheaved straw set up as the target at a distance of 3m, each subject shot an arrow ten times for each bow. Fig. 1 shows an outline of the experimental setting.

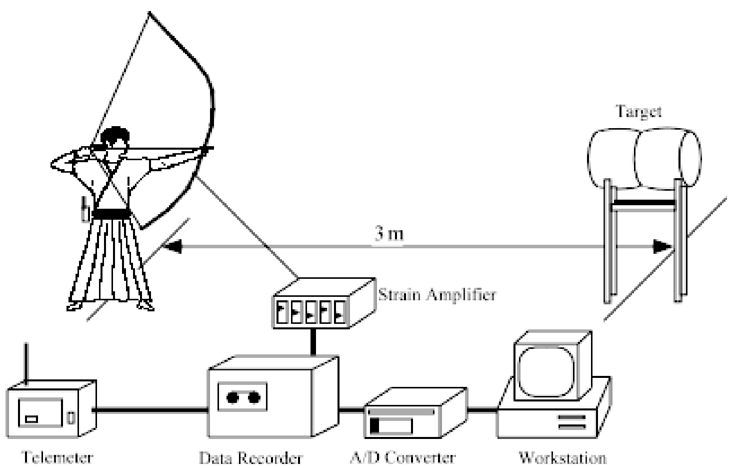


Fig. 1. Experimental arrangements.

Recording of surface EMG

Activities of the following four muscles were recorded during the shooting trials: the extensor carpi radialis longus (ECRL), extensor digitorum (ED), extensor carpi ulnaris (ECU) and flexor carpi ulnaris (FCU) of the left forearm. EMG was picked up with the bipolar detection technique using surface electrodes of 2 mm in diameter of the contact surface. Electrodes were attached to the central part of the venter of each muscle with an adhesive collar at intervals of 2 cm from the center to center of electrodes (Fig. 2). In order to reduce the electrical impedance of the skin, a small amount of epidermis was removed from the skin with a sterilized needle before the attachment of electrodes. The myoelectric signals were amplified with a time constant of 0.03 sec, and A/D converted at a sampling rate of 2 kHz.

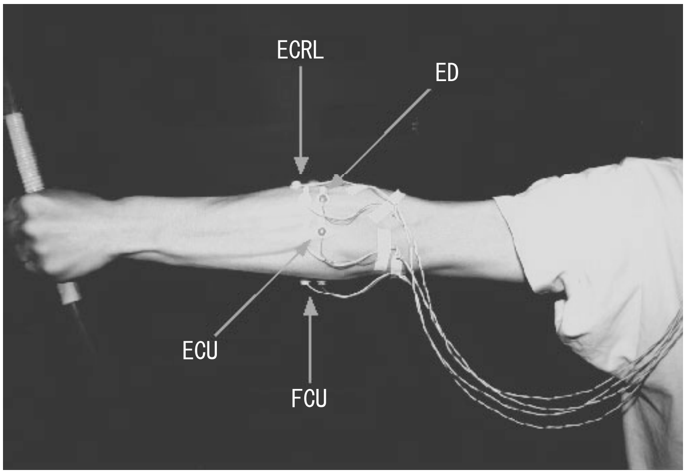


Fig. 2. Surface electrodes attached to left forearm muscles. ECRL: m. extensor carpi radialis longus; ED: m. extensor digitorum; ECU: m. extensor carpi ulnaris; FCU: m. flexor carpi ulnaris.

In order to standardize the myoelectric signals and to check the cross talk between the signals, each subject made the maximum voluntary contraction (MVC) of the above four muscles for about 3 seconds, and EMG was recorded. The MVC was elicited with resisted isometric extension (dorsal flexion) and ulnar deviation of the wrist.

Checking the cross talk of EMG signals

Possibility may exist that contamination, or cross talk, occurs between electrical signals of adjacent muscles in recording EMG from the forearm. It has been established that the degree of cross talk can be evaluated with cross-correlation of myoelectric signals between the muscles concerned, and reliability of the signals is satisfied if the coefficient of the correlation does not exceed 0.3 (Vink et al., 1989; Winter et al., 1994). Thus, correlation coefficients were calculated for MVC activity of three pairs of the adjoining muscles, i.e. ECRL *vs*. ED, ED *vs*. ECU, and ECU *vs*. FCU. As a result, the coefficients averaged across the subjects were smaller than 0.3 in most of the pairs, excluding the case of ECRL *vs*. ED in ulnar deviation, which produced coefficients of 0.39 ± 0.23 (mean ± SD). The latter case may have arisen from the fact that activity level was markedly lower in ECRL than in ED, with a result of a higher similarity in myoelectric signals between the two muscles due to inevitable contamination from ED to ECRL. Since the level of activity appearing in each muscle was substantially high in our experiment as shown below, the influence of cross talk on experimental results was estimated negligible.

Measurements of the mechanical and temporal variables

To measure the torsional and bending torque acting on the bow by the operation of "Teno-uchi", strain gage sensors were installed on the front and rear side of the bow near the grip. The strain was amplified, A/D converted at a sampling rate of 10 kHz, and fed to personal computer. The instants at which the bowstring and arrow separate and the bow is restored to the original condition, respectively, were judged by the behavior of bending torque. To detect the instant of release when the bowstring separates from the right hand, copper foil pieces were installed on the part of the right hand holding the bowstring. The foil pieces constituted a contact switch of a circuit, which was broken by the releasing action of the hand. For details for measuring the mechanical and temporal variables in shooting a Japanese bow, readers are referred to Hosoya and Mori (1992).

Data processing

Myoelectric signals from each muscle were full-rectified, integrated, averaged for the time of observation, and devided by the average integrated value obtained in MVC of the same muscle. By this procedure, EMG data were normalized as %MVC values. To quantify the mechanical features of "Teno-uchi" maneuver, the torsional torque in horizontal plane and bending torque in sagittal plane acting on the bow due to "Nejiri" and "Uwa-oshi", respectively, were integrated for the restoring time. Taking the electro-mechanical delay (Winter and Brookes, 1991) into consideration, the relationships between the muscular activities before release in %MVC and "Nejiri" or "Uwa-oshi" torque acting on the bow during the restoration were analyzed in terms of the cross correlation between these variables.

RESULTS AND DISCUSSION

Activities in left forearm muscles before release and "Teno-uchi" maneuver

Figure 3 shows an example of activities in left forearm muscles observed commonly in the subjects during a period from 0.5 sec before to immediately after release. While the activities in extensors gradually increase toward the release, those in the flexor exhibit an inverse trend.

Figure 4 illustrates relative magnitude (%MVC) of activity in each muscle, averaged for 0.5 sec duration just prior to release in shooting an arrow with the own and experimental bow, respectively. As stated earlier, the latter bow is about 12 % weaker in strength than the former. Irrespective of the strength of the bow, the activity level is highest in ECU, suggesting that the prime mover of the left wrist joint in drawing a bow is ECU. While the relative activities increase in each muscle when shooting with a stronger bow, it is noted that the increment is larger in ED and ECU than in ECRL and FCU. A bow is equipped with torsional as well as bending rigidity. Since ED and ECU are considered to collaborate in twisting the bow horizontally, the EMG observation as above suggests that, with increase in the strength of a bow, coping with the torsional rigidity becomes more critical for the left forearm muscles. Results with a similar trend were observed in all subjects.

To examine muscular activities before release in detail, a period of 0.6 sec including 0.5 sec before and 0.1 sec after release was divided into 6 sections of 0.1 seconds, and mean EMG magnitude in %MVC for each section was obtained. Figure 5 shows the results for a subject. Average activities attain to 60 % MVC in ECRL and ED, and even to as high as 80 % MVC in ECU and FCU early in the period of 0.5 sec before release. A characteristic feature in the figure is that activities in the extensors increase gradually toward release, up to above 100 % MVC in ECU in particular, whereas flexor activity decrease drastically just prior to the release. Following the release, while activities of ED, ECU, and FCU decline remarkably, ECRL alone enhances its activity.

These phenomena in EMG were observed in most of the subjects. The marked activities prevailing early in the pre-release period are considered to be for stabilizing a fully drawn bow. The vigorous activities in ECU and FCU, in particular, suggest that the ulnar flexor and ulnar extensor of the wrist collaborate in exerting substantial moment of ulnar deviation to the bow. On the other hand,

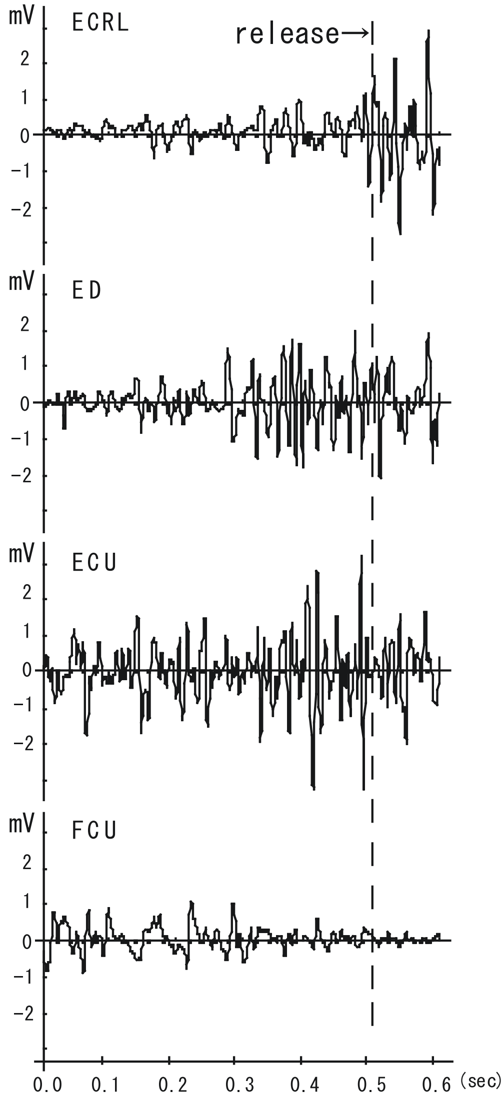


Fig. 3. Electrical activities recorded from left forearm muscles before and after releasing the hold of a bowstring. For abbreviation of muscles, see Fig. 2.

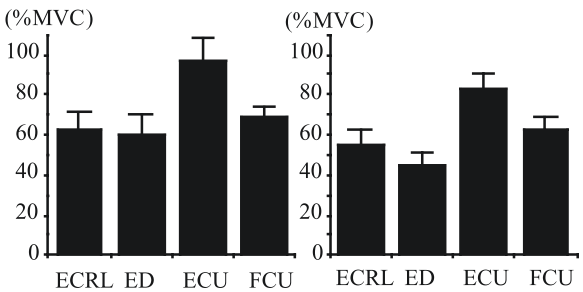


Fig. 4. Relative magnitude of EMG recorded from left forearm muscles of a subject, averaged for 0.5sec duration just before release in shooting the subject's own bow (left) and experimental bow (right). For abbreviation of muscles, see Fig. 2.

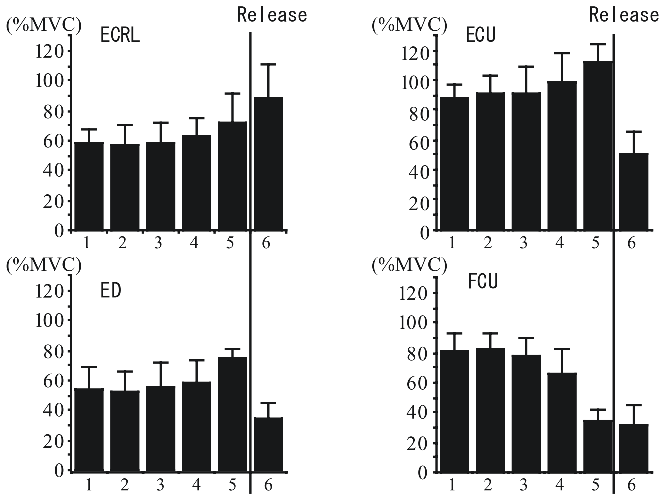


Fig. 5. Relative magnitude of EMG recorded from left forearm muscles of a subject, averaged for the following 0.1 sec intervals before and after release. 1: 0.5 to 0.4 sec before release; 2: 0.4 to 0.3 sec before release; 3: 0.3 to 0.2 sec before release; 4: 0.2 to 0.1 sec before release; 5: 0.1 sec before to the instant of release; 6: the instant of release to 0.1 sec after release Values are mean + SD across 10 shooting trials with the subject's own bow. For abbreviation of muscles, see Fig. 2.

changes in activity level in each muscle toward release may be related with the "Teno-uchi" maneuver mentioned earlier. While gradual increase in extensor activities, in which the enhanced forces coincide in direction with the drawing of a bow, is considered to be associated with "Nejiri", development of activities to supramaximal level in ECU together with drastic reduction of FCU activities are supposed to cause extension-ulnar deviation of the wrist in "Uwa-oshi". The increased activity in ECRL after release appears to be derived from stretch reflex induced by the inertial motion of the bow following the separation.

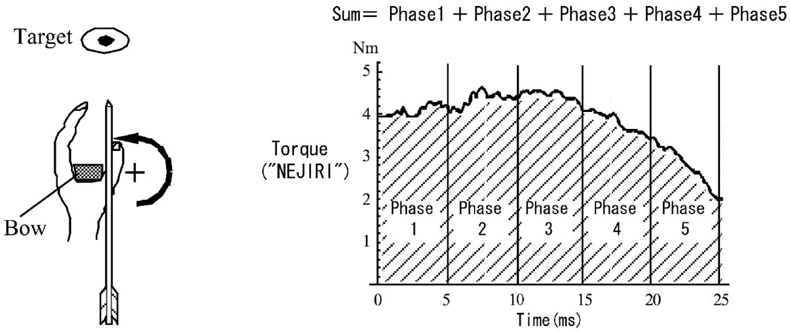
Correlation of pre-release muscle activities with the torque in "Teno-uchi" maneuver

Because it is hard to clarify the mechanism of "Teno-uchi" exclusively through the analyses of forearm muscle activities, correlation was examined for the muscle activities and the torque given to the bow by the archer. Table 1 shows the correlation coefficients between the relative EMG magnitude in each muscle averaged for the period of 0.5 sec before release and the integrated values (impulses) of "Nejiri" torque during the restoring time. The coefficient was calculated for each of the 5 msec intervals in 25 msec restoration. While the correlation is statistically significant and positive in ED and ECU, or significant and negative in FCU, it is almost nonsignificant in ECRL. Extension of the wrist combined with moderate ulnar deviation, caused by cooperation of ED and ECU, is almost similar to the action in "Nejiri". This cooperation associated with suppression of FCU activity may generate a motion by which the "Nejiri" or horizontally twisting torque acts on the bow.

It is also notable that the correlation coefficients, either positive or negative, become higher toward the end of restoration. It has been reported that an increase in the "Nejiri" torque in the latter half of restoring time is related with increase in the speed of an arrow (Hosoya et al., 1994). The characteristic trend in the correlation as above thus suggests that the muscles concerned contribute to an effective execution of "Nejiri".

As for the relationship between EMG and "Uwa-oshi" torque, positive correlation with the torque is seen in the ECU and FCU and negative correlation in the ECRL and ED (Table 2). "Uwa-oshi" maneuver is primarily composed of ulnar deviation of the wrist. Since the latter deviation is produced by synergistic actions of the ECU and FCU, while the ECRL and ED are antagonistic in function, the correlations noted above are reasonable from the anatomical point of view. It is also noted that, in contrast to the case of "Nejiri", the degree of correlation, either positive or negative, is

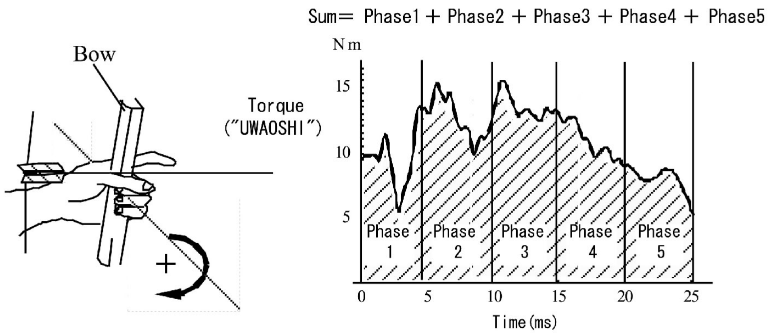
Table 1. Correlation coefficients between the relative EMG magnitude averaged for the period of 0.5 sec before release and "Nejiri" impulse during the restoring time. The coefficient is presented for each of the 5 msec intervals (phases 1 to 5) in 25 msec restoration, as well as for the total restoring time. For abbreviation of muscles, see Fig. 2.



	Sum	Phase1	Phase2	Phase3	Phase4	Phase5
ECRL	-0.073	-0.123	-0.186	-0.148	-0.033	0.235*
ED	0.436***	0.297**	0.273**	0.35**	0.54***	0.702***
ECU	0.354**	0.256**	0.246**	0.314**	0.44***	0.439***
FCU	-0.287**	-0.128	-0.147	-0.24*	-0.378***	-0.55***

* p<0.05
** p<0.01
*** p<0.001

Table 2. Correlation coefficients between the relative EMG magnitude averaged for the period of 0.5 sec before release and "Uwa-oshi" impulse during the restoring time. The coefficient is presented for each of the 5 msec intervals (phases 1 to 5) in 25 msec restoration, as well as for the total restoring time. For abbreviation of muscles, see Fig. 2.



	Sum	Phase1	Phase2	Phase3	Phase4	Phase5
ECRL	-0.341**	-0.397***	-0.31**	-0.287**	-0.352**	-0.316**
ED	-0.395***	-0.491***	-0.506***	-0.415***	-0.281**	0.083
ECU	0.351**	0.427***	0.505***	0.426***	0.192*	0.02
FCU	0.261**	0.349**	0.389***	0.293**	0.125	0.056

* p<0.05
** p<0.01
*** p<0.001

higher in the first half of restoration. This suggests that muscular involvement in the maneuver is managed earlier for "Uwa-oshi" and later for "Nejiri" during the momentary restoration.

Looking at the correlation coefficients in Tables 1 and 2, in addition, it is recognized that actions of the ED and FCU are in a trade-off relationship with respect to the "Teno-uchi" maneuvers; activation and suppression are required in ED for "Nejiri" and "Uwa-oshi", respectively, while vice versa in FCU. Such trade-off relationships are supposed to be actualized through the time-sharing in the muscular involvement mentioned above.

Happening of "Biku" and changes observed in EMG and torque

Figure 6 illustrates incidental changes in EMG and torque accompanying the "Biku", an involuntary resignation from release in shooting an arrow. A clear silent period appears in EMG, and correspondingly, a decline occurs in the "Nejiri" and "Uwa-oshi" torques. "Biku" is not rare in shooting an arrow with Japanese-style bow, but because it is unpredictable in nature, these observations are quite valuable.

The "Biku" happened in 8 out of the 10 subjects in this study, where the silent period appeared exclusively in the extensor or flexor muscle of the wrist. Close analyses of the data have revealed that where a silent period appears in EMG of the ED or ECU, a diminutive change occurs in "Nejiri" torque prior to a similar change in "Uwa-oshi" torque (Figure 6A). On the other hand, such a change occurs earlier in "Uwa-oshi" than in "Nejiri" torque if an EMG silent period appears in the FCU (Fig. 7B). From these observations, it is conceivable that the ED and ECU of the left forearm are closely related to "Nejiri" while the FCU is deeply connected with "Uwa-oshi".

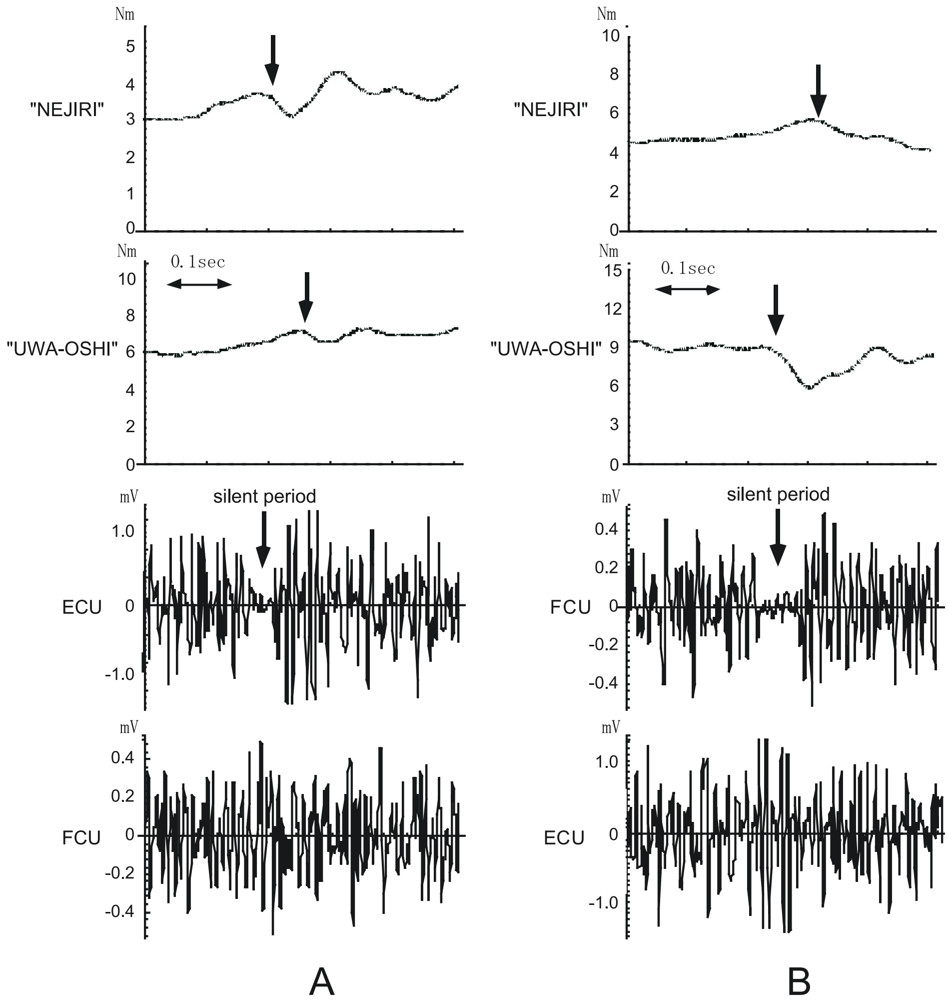


Fig. 6. "Nejiri" and "Uwa-oshi" torque and EMG of forearm muscles recorded in shooting trials where "Biku" happened. A: A silent period taking place in ECU activity and a transient decline of torque appearing earlier in "Nejiri" than in "Uwa-oshi". B: A silent period observed in FCU activity and torque declining earlier in "Uwa-oshi" than in "Nejiri". For abbreviation of muscles, see Fig. 2.

CONCLUSION

The "Teno-uchi" maneuver of Japanese-style archery including the operation of "Nejiri" and "Uwa-oshi" was analyzed by examining the pre-release activities of the left forearm muscles and their temporal changes, correlation between these activities and the torque acting on the bow during restoration, and changes appearing in EMG and torque in association with "Biku" happening. The analyses revealed that activation of ECU/ED and inhibition of FCU brought about "Nejiri", while activation of ECU/FCU and inhibition of ECRL/ED gave rise to "Uwa-oshi", thus causing activities of trade-off nature in ED and FCU for the maneuver. The trade-off activities were presumably actualized through time-sharing coordination between the muscles.

This paper was presented at a symposium 'Adaptation to exercise: An ergological perspective', held on April 29, 2001, in commemoration of the retirement of Prof. Morihiko Okada from the University of Tsukuba.

REFERENCES

Hosoya, S and Mori, T (1992) A study on evaluation of the mechanical characteristics of Japanese bows using energy transfer efficiency. *J. Japanese Academy of Budo*, **25**(2): 24-30 (in Japanese).

Hosoya, S, Shinzaki, S, Mori, T, and Takahashi, M (1994) A mechanical study of "Nejiri" technique in Kyudo: Computer simulation analysis. *J. Japanese Academy of Budo*, **26**(3): 31-40 (in Japanese).

Inagaki, G (1979) Technique of Japanese-style bow, 3. *Shintaiiku*, **49**: 636-643 (in Japanese).

Ono, T (1969) Electromyographic study of the Kyudo technique. *In*: Gendai Kyudo Koza,vol.5, pp.13-23 (in Japanese).

Vink, P, Daanen, HAM, and Verbout, AJ (1989) Specificity of surface-EMG on the intrinsic lumbar back muscles. *Human Movement Science*, **8**: 67-78.

Winter, DA, Fuglevand, AJ, and Archer, SE (1994) Cross talk in surface electromyography: Theoretical and practical estimates. *J. Electromyogr. Kinesiol.*, **4**: 15-26.

Winter, EM and Brookes, FBC (1991) Electromechanical response times and muscle elasticity in men and women. *Eur. J. Appl. Physiol.*, **63**: 124-128.