COORDINATIVE ASPECTS OF ARCHERY - AN APPROACH USING SURFACE-ELECTROMYOGRAPHY

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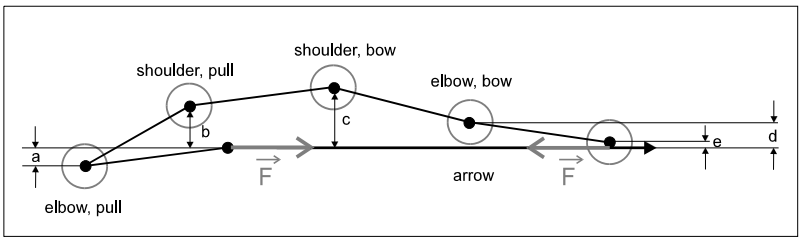
INTRODUCTION: The process of a shot in archery can be described as follows: The archer draws the bow, pulls the arrow to the clicker[1], fixes in this position and aims. Before he releases the arrow, the archer pulls the arrow through the clicker so that a click can be heard. Shortly after this sound, the archer releases. Immediately before the shot there are changes in the muscle activity of shoulder and back. From a biomechanical point of view, the archer must cope with the release of the balance of force between the external tension and the muscular forces (see Fig. 1) immediately after the shot by means of his neuromuscular system. The quality of **the anticipation of the balance's release** strongly



influences the result: After the release of the hand from the string, which also means the release of the static force balance, the arrow still sticks to the string (Leroyer et al. 1993). Thus each motion of the bow is transferred to the arrow. The goal of the archer is to keep the bow steady during and after the release of the balance up to the moment when the arrow leaves the string.

Fig. 1: Schematic figure of an archer's body segments shown from the top. The bow sets its vigor to the hand at the bow's side and the hand of the pull side. The marksman's muscles produce a reaction resulting in a static balance. Hence, there are torques in the joints (circles in the picture). As the distances between the joints and the axis of the arrow increase (distances a,b,c,d, and e) so do the torques, while the forces stay the same. When the hand releases the string, the force F as well as the torques (circles in the picture) immediately decrease to zero.

The aim of this research is to investigate the changes in muscle activity in view of:

- the anticipation of the balances release and
- the function of the clicker in motor control with regard to the question of whether an archer shoots as a reaction to the clicker.

METHODS:

Electromyography: The activity of the neuromuscular system was researched with highly skilled archers of the German National Teams using surface-electro-

[1] *The clicker is a 5 cm long and 0.5 cm wide piece of spring steel fixed to the middle of the bow. When the archer draws the bow, he holds the arrow between the bow and the clicker, so that the clicker presses the arrow laterally against the bow. Before the archer shoots the arrow, he pulls it back until the clicker slips over the arrowhead and causes a click.*

myography (EMG): The EMG of eight muscles (pull: m. extensor carpi radials brevis, m. flexor carpi radialis, m. deltoideus, m. trapezius pars. descendens-transversa, m. trapezius pars transversa, m. biceps; bow: m. pectoralis, m. deltoideus) were acquired for nine marksmen. To synchronize the EMG data to the moment of the click, the moment of the arrows acceleration by means of the string, and the moment when the arrow leaves the string, an acceleration sensor was fixed to the middle part of the bow. Each marksman shot 35 times under the condition of trying to score a bull's eye ("normal shots") and five times under the condition of making an extended shot. An extended shot means, that the period from clicker to release of the arrow increases to more than one second: The archer has to pull the arrow through the clicker and then wait for more than one second before he shoots. Normally he shoots immediately after having pulled the arrow over the clicker. Extended shots are only used in training. The purpose of extended shots is to shoot not as an automated reaction to the clicker but to "shoot consciously and controlled."
Reaction tests: The reaction times to acoustic signals were measured in two tasks: The first task was to keep pressing a key until an acoustic signal was heard. The second task was to keep pressing a key and additionally to fix a laser dot on the golden area of a target as calmly as possible until an acoustic signal was heard. Each condition was repeated ten times. The period between acoustic signal and releasing the finger from the key was measured.
Lengthened arrows: Some arrows (1 of 5) were lengthened by 5 mm without the archers noticing this.

RESULTS:

- The function of the clicker in motor control:

Comparing the EMGs of the shot under the condition of trying to score a bull's eye (normal shot) with those under the condition of an extended shot (see Fig. 2), the EMG patterns show intraindividually a general similarity in their typical diagram (moments and directions of the activation changes). Hence, under both conditions no differences of the activation patterns can be observed, meaning that there is no explicit trigger reaction to the clicker. Further, the periods between the clicker and the shot at normal shots are shorter than the reaction times to an acoustic signal: A comparison between the periods between clicker and shot and the reaction times of the first reaction task shows that for seven of nine marksmen the periods between clicker and shot are significantly shorter (for each marksman: $p < 1\ \%$) than the reaction times of the first task. A comparison between the periods between clicker and shot and the reaction times of the second task shows that for each of the nine marksmen the periods between clicker and shot are significantly shorter (for each marksman: $p < 1\ \%$) than the reaction times of the second task. This leads to the conclusion that the marksmen do not process the feedback of the clicker signal until they have already shot the arrow. Hence the motor program of shooting is already initiated by the marksmen before the click and can be classified as open-loop (see Fig. 3). Thus the click is of no consequence for the release of the current shot, the function of the clicker is only a long term feedback for a constant drawing and a subsequent verification of a correct draw for the previous shot. It can be compared with the sound a tennis player hears when hitting a ball. He can draw conclusions as to the shot he has just made, but can't influence the current movement.

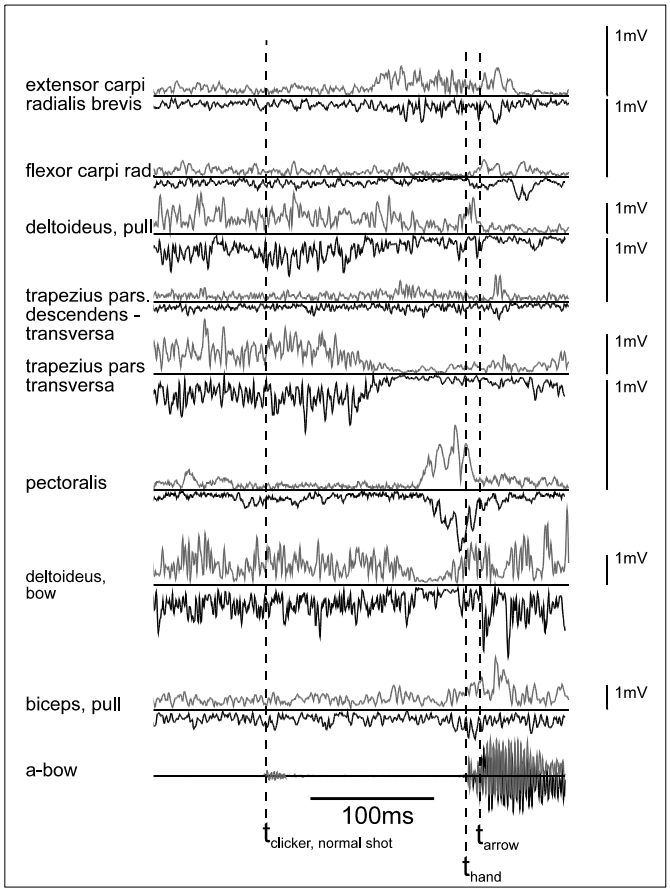


Fig. 2:
Gray: EMGs of a normal shot.
Black: EMGs of an extended shot (the same archer)
At the moment $t_{clicker}$ the marksman has just pulled the arrow over the clicker (only normal shot). At the moment t_{hand} he releases his hand form the string. The arrow leaves the string at the moment t_{arrow}. $t_{clicker}$ and t_{hand} are detected by an acceleration sensor that is fixed at the middle of the bow ("a-bow"). The moment of the release of the arrow from the string (t_{arrow}), as high speed video records show, is 6 to 8 ms before the first maximum deflection of the curve "a-bow".

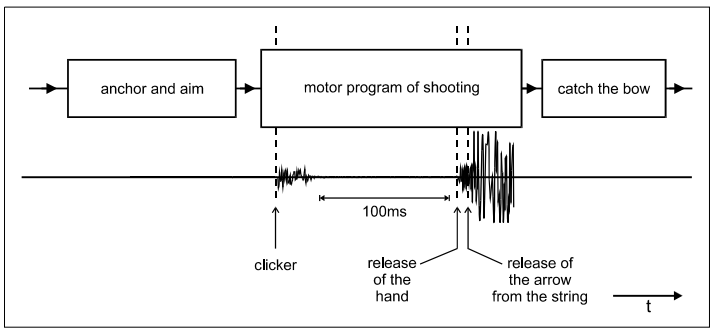


Fig. 3:
The motor program of shooting is initiated before the clicker is heard. It can be classified as open-loop.

- Anticipation of the balance's release:

To analyze the EMG-data with regard to the quality of technique a time-normalized quotient of EMG_V and EMG_K (see Fig. 4) was used. Fig. 5 shows the EMG quotients of nine marksmen: The technique of the release of the force balance is interindividually quite different, a homogenous technique cannot be found. However, it is obvious that the anticipation of the balance's release is characterized by an increasing activity of the m. pectoralis major for all marksmen studied in the

research. The reason for the interindividual differences in technique may be the interindividually different kinegrams, as shown in Fig. 6.

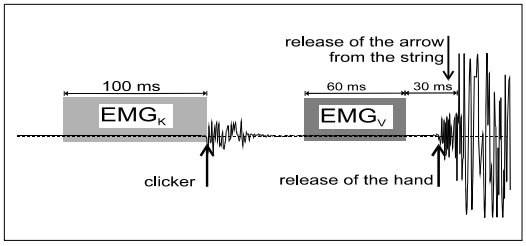


Fig. 4: EMG_V and EMG_K are defined as the integrals of the EMG-data in the periods that are shown in the figure. 30 ms are used with regard to the electromechanical delay (Gollhofer et al., 1996).

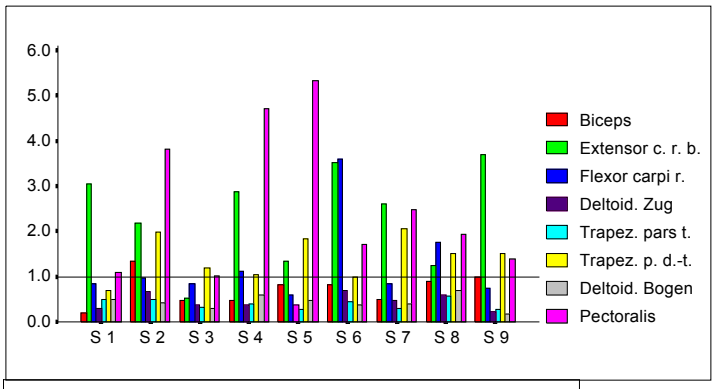


Fig. 5: EMG quotients $(5 \bullet EMG_V)/(3 \bullet EMG_K)$ for nine archers (S1-S9) and 8 muscles each. Each EMG quotient is computed as the average of 35 shots. Values>1 may indicate an anticipation of the balance's release.

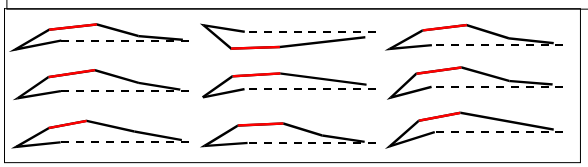


Fig. 6: Kinegrams of nine marksmen shown from the top. (compare Fig. 1).

The different kinegrams can be seen as the result of different anthropometric parameters, different lengths of arrows and the problem of the redundant degrees of freedom. This leads to different torques in the joints (Fig. 1) and hence should be the reason for the different techniques. Thus no homogeneous technique could be found, although the archers are nationally or in some cases even internationally top level.

SUMMARY:

- The motor program of shooting is initiated before the clicker can be heard. Thus it can be classified as open-loop.
- The anticipation of the balance's release is characterized by an increasing activity of the m. pectoralis major.
- Although the archers are nationally and in some cases internationally top level, no homogeneous technique could be found.

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