IF MONO- AND BI-ARTICULAR MUSCLES DO HAVE A DIFFERENT FUNCTIONAL ROLE, IS THEIR ACTIVATION DIFFERENT AND TASK DEPENDENT?

Reaction to G.J. van Ingen Schenau (1989)

C.C.A.M. GIELEN *

University of Nijmegen, The Netherlands


The idea presented in the target article suggests a different role for mono- and bi-articular muscles. More important, the target article shows that bi-articular muscles are very important for the different types of movements that can be made with multi-joint limbs. The apparently contradictory demands on the contribution of various muscles to joint torque and to change in joint angle, as outlined in fig. 10 in the target article, are a problem both for biological and artificial (robot) multi-joint limbs. Therefore, the relevance of this target article exceeds the domain of biological systems which provided the fundamental insight into the coordination of multi-joint limbs.

As the author clearly mentions the explanation for the role of bi-articular muscles is still rather qualitative, and more quantitative research has to be carried out in order to arrive at quantitative predictions that can be compared with experimental observations on muscle activation patterns. However, the qualitative predictions made in the target article are in agreement with some recent observations.

* Correspondence address: C.C.A.M. Gielen, Dept. of Medical Physics and Biophysics, University of Nijmegen, Geert Grooteplein Noord 21, 6525 EZ Nijmegen, The Netherlands.

reported in the literature. Hoffer et al. (1987) found a single burst of activity in mono-articular muscles in the cat hind limb during each cycle of a normal walking pattern. However, a bi-articular muscle, such as m. sartorius anterior, revealed three distinct bursts of activity in each step cycle, one during knee extension (stance phase), one during knee and hip flexion (early swing phase) and another during knee extension combined with hip flexion (late swing phase). These different bursts of activity may be understood partly as assisting the activation of mono-articular muscles acting across the knee and hip in a way compatible with the suggestions presented in the target article.

Other data that are relevant in the context of the target article have been presented by Karst and Hasan (1988). They showed that elbow flexion in planar arm movements that involve the shoulder and elbow, is not always initiated by EMG activity in all elbow flexor muscles. The null-hypothesis of Karst and Hasan that all flexion movements were initiated by EMG activity in flexor muscles was violated in their study were they considered the bi-articular muscle biceps brachii, caput longum, as a flexor for the elbow and shoulder joints. Similarly, elbow extension movements were not always initiated by extensor muscles. An alternative hypothesis, that the initial muscle activity should be related to torque in movement direction, could also be rejected. If the hypothesis put forward in the target article is correct, then it predicts quite a different role (and therefore also a different activation) for mono- and bi-articular muscles both acting across the same joint. In this view, the results of Karst and Hasan, who lumped together the data from mono- and bi-articular muscles, may not be surprising and their results would become more easy to understand if a clear distinction had been made between the activation of mono- and bi-articular muscles. Whether the experimental observations of Karst and Hasan (1988) are also quantitatively in agreement with the predictions that follow from the ideas presented in the target article, remains to be seen.

One of the statements in the target article is that mono-articular muscles deliver force primarily during the phases where the muscles shorten, thereby contributing to positive power. The main function of the bi-articular muscles would be to assist the mono-articular muscles and, if necessary, to transfer power from one joint to another. As in the artificial system used by the author to illustrate and explain his ideas (see fig. 7) the bi-articular muscle should be very stiff during the movement against a load: it should be held at approximately the same
length during the movement. Accomplishing this task requires either a very precise coordination of mono- and bi-articular muscles, or it might be achieved by reflex actions which have been shown to be important for stiffness regulation (Nichols and Houk 1976; Hoffer and Andreasen 1981). If reflex-actions are important in movement control then reflexes in mono- and bi-articular joints may serve a different purpose: the mono-articular muscles should shorten while the bi-articular muscles should generate torque and at the same should shorten or should remain at a more or less constant length, depending on the direction of force exerted by the limb and on movement direction (see fig. 7). Therefore, the effect of reflex actions may be different in mono- and bi-articular muscles. This target article may provide an explanation for the contradictory findings that have been reported in the literature about reflex actions and muscle receptor activity in different muscles and in different experimental conditions (see e.g. Stein 1982; Hoffer et al. 1987). Considering the role of short- and long-latency reflex components and the role of the long-latency reflex component in the coordination of movements (Gielen et al. 1988) the most important reflex component to study with regard to the different role in mono- and bi-articular muscles would be the long-latency reflex component.

With regard to fig. 9 one might wonder whether the activation of muscles is the same in isometric contractions and during movements against a load. In fig. 9b the activation of monoarticular hip flexors and knee extensors, as well as the activation of m. rectus femoris gives rise to isometric force in the direction of \( F_1 \). The activation of a hip extensor, which is necessary in order to make a movement in the direction indicated by \( F_2 \) would not be very efficient for isometric contractions. This suggests that, depending on the task (isometric contraction versus isotonic movement), the activation of muscles may be different.

Recently (Tax et al. 1989) experimental evidence has been provided that the relative activation of muscles, and thereby their relative contribution, is dependent on the type of task. For example, Tax et al. found that the recruitment threshold of motor units in the bi-articular m. biceps (caput longum) decreases during movement as compared to the recruitment threshold of the same motor units in isometric contractions. Moreover, the recruitment threshold of motor units in the mono-articular m. brachialis was found to be raised during isotonic movements compared to the isometric condition. These differences
were already found at very low movement velocities (2 deg/s flexion in the elbow joint) and therefore seem to point to a discontinuity in the muscle activation pattern of elbow flexors at zero velocity (isometric versus isotonic) rather than to an effect of the force–velocity relationship. More detailed research will be necessary to investigate whether the differences in motor-unit activity during isometric contraction and isotonic movements can be explained completely by the above reasoning.

It is interesting to note that the three bursts of activity, observed in m. sartorius anterior in the three different phases of the step cycle in cat (Hoffer et al. 1987) were found in different groups of motor units. Although the sartorius muscle was activated three times during a single step cycle, each motor unit was activated only once during the step cycle. This indicates that the motor-unit population in m. sartorius anterior consists of three functionally separate motor-unit groups, each of which is independently activated to contribute to one of the three tasks mentioned above. A segregation of the motor-unit pool of a single muscle in more sub-populations, each of which receives a very distinct and different activation, has been reported before (e.g. Ter Haar Romeny et al. 1982; Van Zuylen et al. 1988). These observations indicate that the notion of homogeneous activation of all the motoneurons of a single muscle (Henneman 1981) is not correct. For some muscles the segregation in sub-populations could be explained on the basis of the different mechanical advantage of motor units (see e.g. Loeb 1985). However, Ter Haar Romeny et al. (1984) found that the mechanical advantage of motor units in different sub-populations of motor units in the human biceps brachii (caput longum) was the same. Therefore, the mechanical advantage of motor units cannot always explain the existence of different sub-populations of motor units and for the motor units in the human biceps brachii there must be another explanation. A new hypothesis to explain the different activation of various sub-populations of motor units in a single muscle may be related to the different contribution of mono- and bi-articular muscles in multi-joint limbs in isometric and isotonic contractions. Whether the ideas put forward in the target article do, indeed, provide a good functional explanation for the existence of different sub-populations is open to experimental verification.

The (different?) activation of mono- and bi-articular muscles during isometric and isotonic movements is also of relevance for hypothetical
models for movement control. One of the most frequently cited models (the \(\lambda\)-model of Feldman (1986)) assumes that one single parameter may explain the muscle activation both for isometric contractions and for all voluntary movements. This parameter corresponds to the threshold of muscle activation or, in other words, it corresponds to the lower muscle length for which the muscle is activated. Once this threshold parameter is defined, the activation of muscle as a function of muscle length is completely determined. If the hypotheses of the \(\lambda\)-model described by Feldman (1986) are correct, then a single muscle activation pattern should be found for all motor tasks, contrary to the suggestions made in the previous paragraph and contrary to the experimental observations of Tax et al. (1989). In order to maintain the \(\lambda\)-model of Feldman as a useful and valid model, the ‘equilibrium point’ of the limb is the result of a set of different thresholds for all muscles. These thresholds have to change differently for mono- and bi-articular muscles during movements, since a change in force or in limb position has to be translated into changes in muscle force or muscle length, which are different for mono- and bi-articular muscles. Therefore, the shift of the threshold in antagonistic mono- and bi-articular muscles does not have to be in opposite directions, such that the agonist muscle will shorten and such that the antagonist muscle will lengthen. It seems that the equilibrium point of the limb may reflect an internal representation of ‘desired’ limb position in world space which is transformed into a set of thresholds for all the muscles involved in a higher dimensional muscle space. In this view the equilibrium point for a particular muscle is not directly related to the equilibrium point of its antagonistic muscle, but can be understood only in relation with the equilibrium point of all other muscles acting on the limb (cf. the results on muscle activation in the human arm as described by Van Zuylen et al. (1988)). If the change in equilibrium point for each muscle is proportional to the contribution of each mono- or bi-articular muscle to the movement, the ideas in the target article are not necessarily in contradiction with the (modified) \(\lambda\)-model. However, new experimental results are necessary to give the final answer.

Like any good idea, it may solve some problems but it may also raise quite a lot of new questions. Both are certainly true for this target article. In my view the hypothesis about the role of mono- and bi-articular muscles will probably elicit a lot of experiments in the already exciting field of motor control with interesting applications in various other areas such as sport and robotics.
References


