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Modulation of stretch reflex by anticipation of the stimulus through visual information

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Summary. A stretch stimulus was applied to the right elbow flexor by the free gravitational fall of a weight. The subject was instructed to flex the elbow joint to lift the weight quickly (resist task) or to extend the elbow joint to overtake the falling weight (assist task) as the voluntary reaction to the stretch stimulus. In the resist task, when the subject could predict the time of stretch stimulus onset by watching through the mirror the behavior of the experimenter going to give the stretch stimulus, the integrated EMG (I-EMG) of M 2 (50–80 ms after the stimulus onset) and M 3 (80–100ms) components of stretch reflex were significantly enhanced compared with when the experimenter's movements were invisible to the subject, while no differences were observed in the background discharge before the stretch stimulus onset (BGA) and the short latency reflex (M 1). In the assist task, the M 2 and M 3 were depressed when the visual information about the stimulus presentation was available, while the BGA and M 1 were unchanged. From these results, it is suggested that (1) the preparatory set should be classified into two categories, i.e., task-related "topographical set" and timing-related "chronographic set", and (2) visual information about the process of stimulus presentation can modulate the reflex activity of stretched muscle allowing the required task to be executed efficiently by accurately anticipating the stretch stimulus onset.

Key words: Long latency stretch reflex – Stimulus anticipation – Preparatory set – Reflex modulation

Introduction

It is now widely accepted that the stretch reflex is composed of short latency and long latency components since Hammond (1954, 1956, 1960) and Hammond et al. (1956) found the short latency reflex (latency about 15–20 ms) and the long latency reflex (45–50 ms) elicited in the elbow flexor by the pull of the wrist. Similarly, Marsden et al. (1978, 1981) reported that the sudden load change imposed during the isometric flexion of the thumb produced the short latency spinal reflex of 25 ms latency as well as the long latency reflex of 40–55 ms latency. Agarwal and Gottlieb (1980) also reported that the torque suddenly applied about the ankle joint elicited the short and long latency stretch reflex in the leg muscle.

The gain of the long latency component of the stretch reflex is known to be modified according to the requested task movement. Hammond et al. (1956) and Hammond (1954, 1956, 1960) originally demonstrated that large long latency reflexes appeared when the instruction to "resist" against the pull had been previously given to the subject, whereas they decreased following the instruction to "let go" (i.e., not to resist). Lee and Tatton (1975) showed that the reflex which commenced about 55–65 ms after the joint displacement was larger when the subject was instructed to "actively" recover the original joint position in comparison with when the active reaction was not requested. Evarts and Tanji (1974, 1976) reported that, in the monkey, also, the intensity of the long latency reflex in the biceps brachii muscle depends on the direction of intended movement, i.e., push or pull of the gripped handle. These studies present the widely accepted general rule on the relationship between stretch reflex and task-related "preparatory set". Namely, the long latency stretch reflex of any one muscle is enhanced when the activity of that muscle promotes the task execution and inhibited when the activity of that muscle prevents the task.

In these studies, the subject's "preparatory set"

Offprint requests to: T. Ohtsuki (address see above) about the task (use or not use some particular muscles) was established sufficiently long enough before the stretch stimulus is applied. Therefore, the "set" which influences the stretch reflex is necessarily long-lasting and enduarable bias of neuronal excitability in its own nature. This kind of "set" may be called "topographical set" in the sense that such and such a muscle should be used in such and such a task. However, in the daily life and sports activities, in addition to this "topographical set", we often use another kind of set, i.e., "chronographic set", which can be made by means of temporal anticipation, as in many so-called "timing" tasks.

It should be noticed that this temporal anticipation is often established through visual information about, e.g., the movements of the target to be caught or the changes of the external environments.

The present study was designed to investigate whether the anticipation about the "time of onset" of stretch stimulus established through visual information can affect the stretch reflex intensity when the intended task movement is kept the same.

Methods

Subjects

Fifteen normal healthy female university students, aged between 18 and 23 (mean 20.9) years, served as subjects. They were all right handed (mean L.Q. $= 86.17 \pm 26.40$) according to the Edinburgh Handedness Inventory by Oldfield (1971).

Apparatus

The arrangement of experimental apparatus is shown in Fig. 1. The ergometer was fixed on the experimental table. The lever arm of the ergometer was connected to the right wrist of the subject with the chain and force transducer. The force transducer was placed between the lever arm and the wrist. The chain was made parallel to the surface of the experimental table by adjusting the position of the clasp attached to the lever arm. The lever arm was attached to the cog wheel of the ergometer, so that when the cog wheel turned, the lever arm moved. The load was hung from the end of the chain around the cog wheel, and held by the string which was tied to the cog wheel and pulled by the wire reel on the wall. The length of the string was adjusted so that the lever arm was held at a right angle. When the string was cut, the load started falling down and at the same time the lever arm started moving forward and the subject's wrist was pulled forward away from the subject. By this apparatus, the stretch stimulus was given to the right elbow flexor muscles of the subject.

The goniometer was attached to the axis of rotation of the lever arm to record the angle of the lever arm. The angle of the lever arm indicates the angle of the elbow joint of the subject.

A mirror was placed in front of the subject, so that the subject, without turning the eyes, head, trunk or any other part of the body, could see through the mirror the string which held the load and the hand movement of the experimenter cutting the string. Thus the subject could get the visual information about the stimulus presentation. In some trials, however, the mirror was covered with a black curtain with one white point on its center. On such trials, the subject could not get the visual information about the stimulus. A screen (the height was about 35 cm) was set between the subject and the string, in order that the subject could not see directly the string and the cutting behavior.

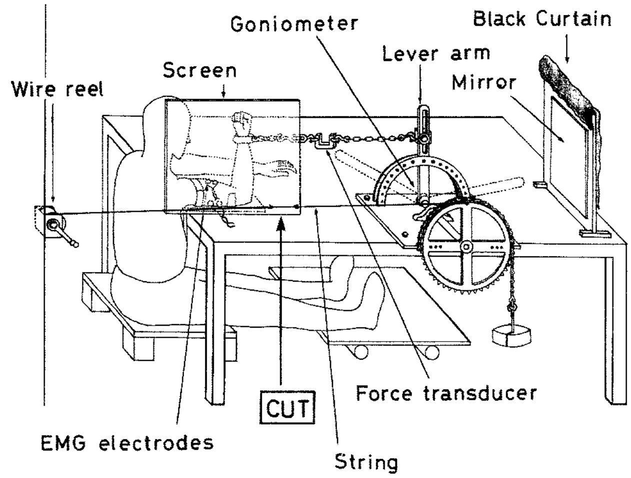

Fig. 1. Schematic representation of the measuring apparatus and experimental arrangements. The string holding the load was cut at the arrow to give the stretch stimulus

EMG recording

Overall electrical activity of the right elbow flexor (biceps brachii) and the extensor (triceps brachii) were recorded with bipolar surface electrodes 5 mm in diameter.

Subject's posture

The subject was kept seated on a wooden experimental chair. The subject's trunk was kept erect with the front of the trunk faced to the ergometer. The axilla was tightly pressed against the edge of the arm holder and the subject held a thin plastic plate between the axilla and the arm holder. The upper arms were kept horizontal and parallel to each other on the experimental table. In the initial position, the right elbow joint was flexed at a right angle. The forearm was kept supinated and the fingers were flexed to make a soft fist during experiment. The wrist ring was attached to the right wrist and was connected with the lever arm. The left arm was laid straight and the palm touched the surface of the experimental table. The legs of the subject were extended and put on the wooden board on the two iron pipes so that the subject could not push the floor by the foot to add the force to resist against the pull of load. The subject was given the instruction to watch the mirror when the mirror was uncovered or to watch the white point on the curtain when the mirror was covered, and not to pull the trunk or the whole arm backwards. Thus the subject's posture was kept constant throughout the experiment.

Experimental design and procedures

The two experimental conditions, "visible" and "invisible" were prepared. For each condition, two kinds of tasks, i.e., "resist" and "assist" were performed.

In the "visible" condition, the experimenter's movement to cut with the scissors the string holding the weight was "visible" through the mirror. Thus the subject could anticipate the time at which stretch stimulus was given, though there was no special instruction to try to anticipate the time of stimulus onset. When the oral signal of 'Ready' (Youi, in Japanese) was given by the experimenter, the subject took the initial position and waited the stretch stimulus with the gaze kept on the front mirror. A few seconds after the oral signal, the experimenter cut the string to give the stretch stimulus. In the resist task, as soon as the subject felt that the wrist was pulled away from the body, the subject should flex the elbow joint to lift the load back as quickly as possible. The lifting movement by elbow flexion was mechanically stopped at 150° of elbow joint angle (0° indicates full extension). When the load was too heavy for the subject, elbow joint could not flex. This unintended elbow extension was mechanically stopped at 10° to avoid injury to the pulled wrist. In the assist task, the subject was asked to intentionally extend the elbow joint of the pulled arm as quickly as possible when the subject felt that the arm was pulled.

In the "invisible" condition, the subject was instructed to take initial position with the gaze kept on the white point on the curtain after the oral signal was given and to wait the stretch stimulus. Thus the the experimenter's cutting movements were "invisible" and consequently the subject had to anticipate, if they wanted to do so, the stretch stimulus presentation without the aid of visual information. Other procedures were the same as for the "visible" condition.

All the fifteen subjects performed exclusively the resist task in the first experimental session. In this session, the wrist was pulled by the two kinds of load, i.e., 25% (light) and 50% (heavy) of the maximum voluntary isometric strength of elbow flexion. Maximum strength was the mean of the two measurements, with the elbow angle of 90°, made before the experimental session. The condition (visible or invisible) and the load (light or heavy) was informed to the subject orally before the trial began. Each condition was performed twice for each load so that eight trials in total, which were randomly ordered, constructed one run. Five runs were carried out for each subject. Therefore, there were twenty trials for each condition for each subject.

Two of the fifteen subjects also volunteered in a second experimental session on different days. In the second session, both the assist task and the resist task was performed with only one load condition (40% MVC). The assist task was performed four times and the resist task was performed twice for each of the "visible" and "invisible" conditions, so that twelve trials in total, which were randomly ordered, constructed one run. Five runs were carried out for each subject. Therefore, there were twenty trials in the assist task and ten trials in the resist task.

The subject was not allowed to make any premature muscle contractions before the arm was stretched. If the subject exerted muscle strength intentionally to lift the load before the stimulus was given, the lever arm clearly moved towards the subject with very small resistance, since the load was held by the string which has some elasticity. Such a trial was declared void and was repeated again. Thus, premature reactions were completely prevented.

Treatment of data

All experimental data, i.e., elbow angle, force, EMG of biceps brachii and triceps brachii were recorded on the ink-writing oscillograph (Nihon Kohden RM-85 polygraph), and simultaneously recorded using a data recorder (Sony DFR 3915). The data thus obtained were converted to the digital values at the rate of 1000 points per second and analyzed using a digital computer Signal Processor 7T17 (Nihon Denki Sanei).

Determination of the onset time of stretch stimulus

The time of the onset of stretch stimulus was determined as the time of the brisk change in the force curve for each trial as follows.

$$\bar{X}_j = 1/100 \sum_{i=j}^{j+99} X_i \qquad \mathrm{SD}_j = \sqrt{\frac{\sum_{i=j}^{j+99} X_i^2 - \left(\sum_{i=j}^{j+99} X_i\right)^2 / 100}{99}}$$

$$\frac{X_{j+99+k} - \bar{X}_j}{\mathrm{SD}_j} \geqq 3.62, \qquad k = 1, 2, \ldots, 10$$

$$Z = 3.62, \qquad P < 0.0002 \tag{1}$$

In these equations, one point refers to 1 ms of time and X means the digitized value of input record. When the consecutive ten points satisfied the Eq. (1), the first point of the ten, $j+99+1$, was regarded as the point of the stretch stimulus onset (Fig. 2). If the ten consecutive points did not satisfy (1), the initial point j was changed to the next point, $j+1$, and the same calculation was repeated.

In most trials, this point could be easily determined from the force curve as shown in Fig. 2. In a few trials, however, it could not be determined because of no brisk change of the force. In such exceptional cases, an alternative method was employed as follows. First the point of the angle change was searched for all trials in the following way.

$$\bar{X} = 1/120 \sum_{i=0}^{119} X_i \qquad \mathrm{SD} = \sqrt{\frac{\sum_{i=0}^{119} X_i^2 - \left(\sum_{i=0}^{119} X_i\right)^2 / 120}{119}}$$

$$\frac{X_{119+l+k} - \bar{X}}{\mathrm{SD}} \geqq 3.62, \qquad k = 1, 2, \ldots, 10 \quad l = 1, 2, 3, \ldots$$

$$Z = 3.62, \qquad P < 0.0002 \tag{2}$$

When the consecutive ten points satisfied (2), the first point of the ten, $119+l+1$, was regarded as the first point of the angle change. As shown in Fig. 2, there was a considerable difference in the first point of change between the angle and

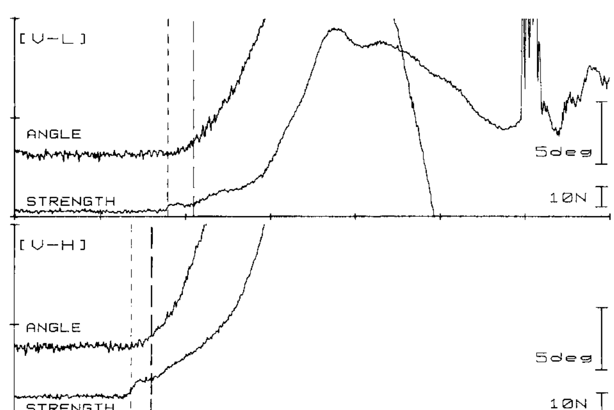

Fig. 2. Examples of the records in which the time of stretch stimulus onset could be determined as the onset of strength change. In each set of traces, upper trace, angle; lower, strength; ----, the time of strength change, i.e., stretch stimulus onset; — — —, the time of angle curve change. Abscissa of each trace is graduated in 100 ms. V–L, visible-light load; V–H, visible-heavy load

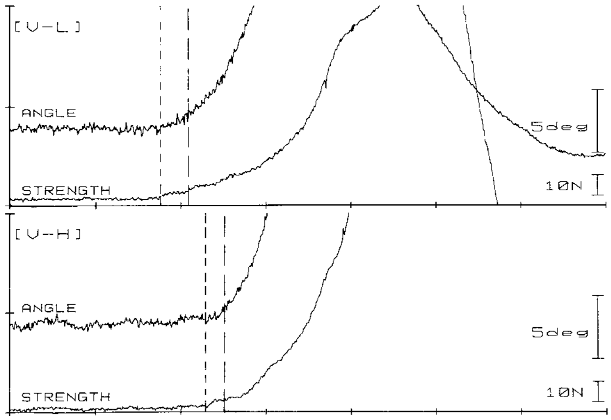

Fig. 3. Examples of the records in which the time of stretch stimulus onset could not be determined from the strength curve. -----, the time of the angle curve change; — — —, the time of stretch stimulus onset which was determined from the angle curve

force. The mean difference between the point of the angle change and the point of force change was calculated for every condition from trials in which the point of force change could be determined. The mean angle-force difference thus obtained was subtracted from the point number of the angle change of the trial in which the point of force change could not be determined. As shown in Fig. 3, this procedure produced acceptable results. Therefore, the point thus obtained was considered as the point of the stretch stimulus onset.

Results

Figure 4 shows the typical examples of the recorded traces of conditions "visible" and "invisible" with a heavy load in the resist task of the first experimental session. About 15 ms after the stretch stimulus onset, the diphasic EMG response (●) appears and about 50 ms after the stimulus the

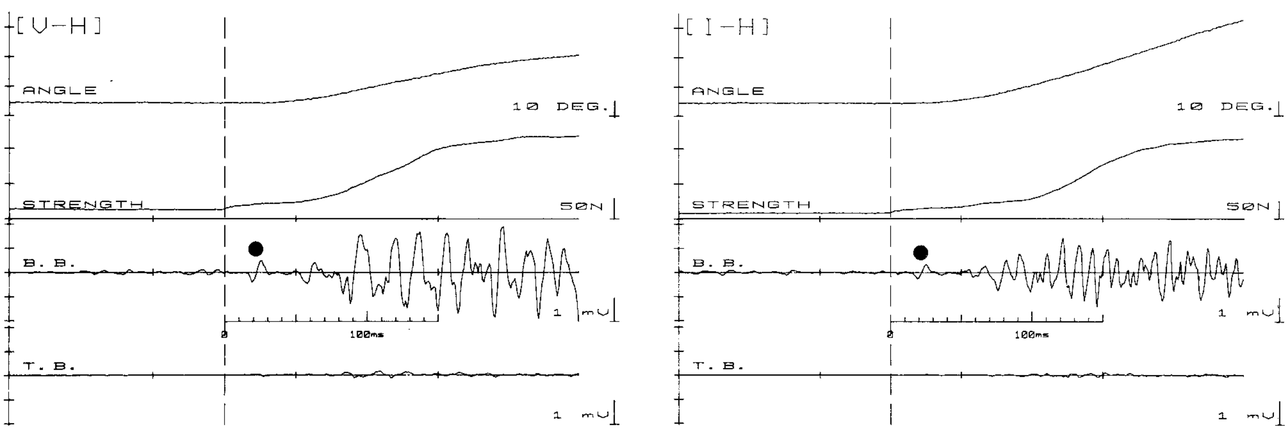

Fig. 4. Typical examples of records obtained from the resist task. In each set of traces, the top trace, the angle of elbow joint (upward deflection indicates extension); second, strength; third, surface EMG of the elbow flexor (m. biceps brachii); fourth, surface EMG of the elbow extensor (m. triceps brachii); vertical broken line, the onset of stretch stimulus; ●, short latency diphasic responses. V–H, visible-heavy load; I–H, invisible-heavy load

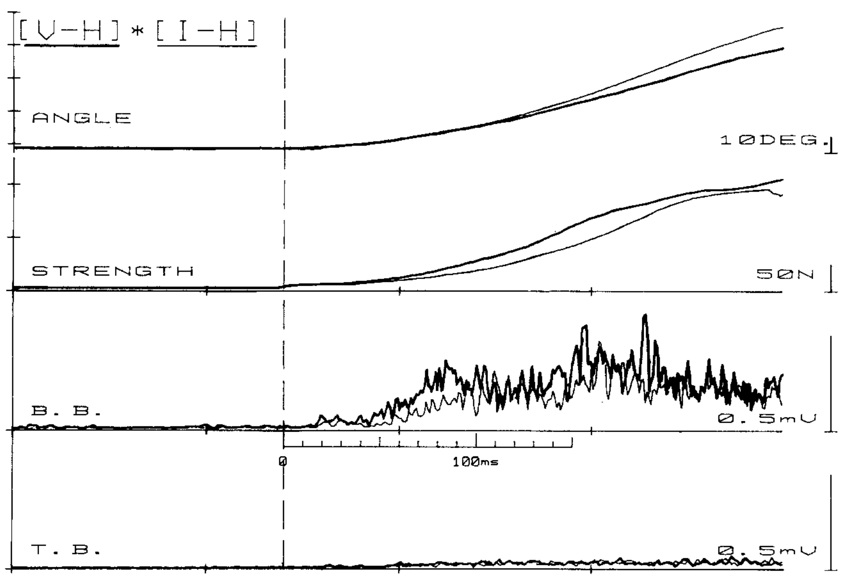

Fig. 5. The typical examples of the averaged records (ten trials) in the resist task superimposed for condition visible (—) and invisible (—). EMG records are full-wave rectified and then averaged. For other legends see Fig. 4

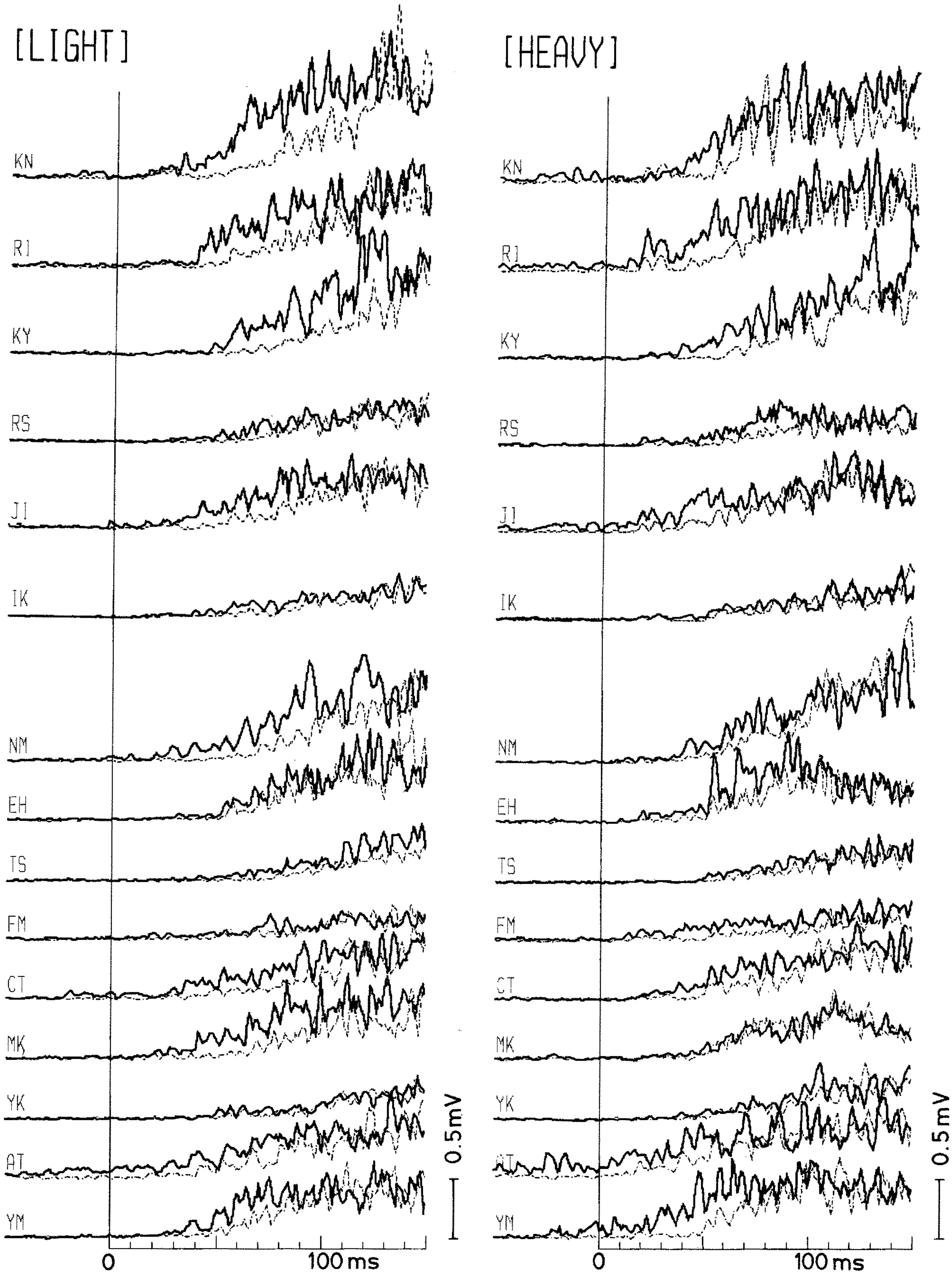

Fig. 6. The averaged EMG records of the elbow flexor obtained from every subject in the resist task. Conditions "visible" (——) and "invisible" (–·–) are superimposed. The vertical thin lines indicate the stretch stimulus onset

second activity wave appears in the biceps brachii muscle in both conditions.

All of these records were averaged for each condition for each subject. EMG was full-wave rectified and averaged. Figure 5 shows the typical examples. Two conditions of visual information are superimposed. As shown in this figure, the elbow angle (upward deflection indicates an extension) of both conditions showed a similar change in the early stage (0–100 ms) after the stimulus onset. But later, the elbow angle increased more slowly in the "visible" condition than in the "invisible" condition. The force increased more quickly in the "visible" condition after 50 ms from the stimulus onset. This implies that the movement to lift the load back was performed more quickly with visual information about the stimulus presentation. As would be expected from these observations, the EMG activity of the biceps seems to be larger with visual information than without. No clear difference was observed in the triceps between the two conditions. The same trends were also observed with the light load.

Figure 6 shows the averaged full-wave rectified EMG of the biceps for every subject. The small short-latency EMG response at about 15 ms after the stretch stimulus is observed in the six subjects from the top in the "visible" condition with a heavy load. The second activity period begins about 30–50 ms after the onset of stretch stimulus in the "visible" condition and about 50 ms or more after the stimulus in the "invisible" condition. The amplitudes of these second activities are obviously higher with visual information about the stimulus presentation than without. The difference was especially large from the stimulus onset till about 100 ms.

To quantify this difference in the agonist muscle activity, the integrated EMG (I-EMG) was measured on every trial. The integration periods were determined as follows (Fig. 7). Although the subjects were instructed not to make strong contraction of the agonist muscle before stretch, a small amount of discharge was necessary for suspending the weight (about 250 grams) of force transducer plus wrist band and chain. Therefore, the I-EMG of the period of 100 ms preceding the onset of stretch stimulus was measured as the background activity (BGA). The duration of the short latency small (two-peak) response after the stimulus was measured from the averaged curve of each condition by the experimenter's visual inspection for each subject. The mean value of this duration for each subject was calculated over the conditions in which the short latency two-peak response was

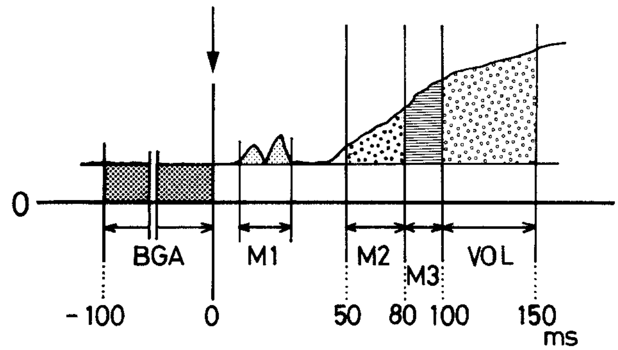

Fig. 7. Schematic representation of I-EMG measurement. The integration periods are shown by horizontal arrows. The vertical arrow at 0 ms indicates the stretch stimulus onset. The I-EMG of each period was calculated by subtraction of the BGA from the raw I-EMG of each period

Table 1. The mean time-period of the short latency two-peak response of each subject

Subject	Time from stimulus onset (ms)	Duration (ms)
RI	15–30	15
RS	16–35	19
IK	13–36	23
KN	15–30	15
JI	15–29	14
KY	16–34	18

evoked (see Table 1). This intraindividual mean value was used as the integration period of the two-peak response of that subject through all conditions. The I-EMG of this period was termed M 1. The mean duration of M 1 period (15–32 ms) calculated from individual mean periods of six subjects listed in Table 1 was used when the subject did not show the distinct short latency two-peak response. In the present experiment, the responses which correspond to the long loop reflexes such as M 2 and M 3 reported in the previous studies, did not appear separately. Therefore, the integration periods for M 2 and M 3 in the present experiment were determined from the latencies of these components reported in the previous studies (see Table 2) as follows.

The component of M 2 was expected to appear during the period from 50 to 80 ms after the stimulus onset. And the component of M 3 was expected to appear between 80–100 ms after the stimulus onset. The integration period for the voluntary contraction component (VOL) was determined as the period from 100 to 150 ms, since in the present experiment the force reached its peak about 150 ms

Table 2. The latencies of EMG responses to the stretch stimulus in the upper limb reported in the previous studies

Author(s)	Year	Muscle	Latency to the onset of EMG activity (ms)				
			Short latency response	Long latency responses			Voluntary response
Hammond	1954	biceps brachii	18				
Hammond et al.	1956	biceps brachii	15–20				
Hammond	1960	biceps brachii	15–20		45–50	71.5	
Lee & Tatton	1975	wrist flexor and extensor	28–32(M1)		55–65(M2)	85–95(M3)	
Marsden et al.	1976	flexor pollicis longus			50		90
Thomas et al.	1977	biceps brachii	25(M1)		50(M2)		100-(Third response)
		triceps brachii	25(M1)		50(M2)		100-(Third response)
Marsden et al.	1978	flexor pollicis longus	24(SP)	40(A)	56(B)		99
Wadman et al.	1980	biceps brachii	16(M1)		55(M2)		115
		triceps brachii	16(M1)		55(M2)		115
Marsden et al.	1981	flexor pollicis longus	25(SP)	40–50(LL)			
Tarkka	1986	triceps brachii	12.5(M1)		64.1(M2)	90	

after the onset of stretch stimulus in the earliest example. The I-EMG of the BGA was subtracted from that of the other four components for every trial (see Fig. 7).

To reject the influence of the background activity of alpha motoneuron pool prior to the stretch stimulus, the paired-sample student t-test was applied and the subjects whose BGA was different at the 0.10 level of significance between the "visible" and "invisible" conditions were excluded. Thus, eight (RI, KY, RS, IK, FM, MK, YK, YM of Fig. 6) and seven (KY, IK, NM, EH, TS, CT, YK) subjects were employed in the quantitative analysis for the light and heavy load conditions, respectively. The intraindividual mean force actually applied to the force transducer by BGA for these subjects was from 1.5 to 13.3 N and the forearm length from wrist to elbow joint was within a range between 20 and 27 cm. Thus, the mean torque about the elbow joint may be between 0.3 and 3.6 Nm. Figure 8 shows the means and S.D.s of I-EMG of each component. In BGA and M1, no clear difference can be found between conditions "visible" and "invisible". In contrast, M2 and M3 in the "visible" condition were larger than "invisible" for both loads. Three factor analysis of variance was applied to test these differences between the two conditions. The factors were subject (A), run (B) and condition (C: visible/invisible). The main effect of factor C was significant for M2 and M3 for both loads (light, M2, $F=18.70$, $P<0.01$; M3, $F=10.60$, $P<0.05$, df$=1,7$; heavy, M2, $F=14.59$, $P<0.01$; M3, $F=16.98$, $P<0.01$, df$=1,6$), but nonsignificant for BGA, M1 and VOL.

Figure 9 shows the typical examples of averaged records obtained from the assist task in the second experimental session. This figure, also, clearly shows the difference between the conditions with and without visual information about stimulus presentation. The force begins to decrease about 100 ms after the stimulus onset in the "visible" condition while it is still increasing in the "invisible" one. Since the force transducer is inserted

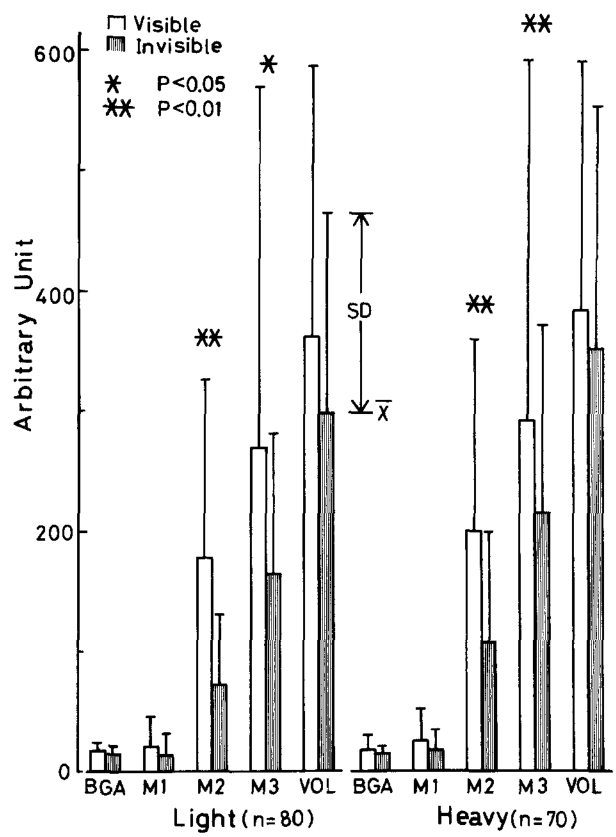

Fig. 8. The means and standard deviations of the I-EMG of each integration period in the resist task of the first experimental session

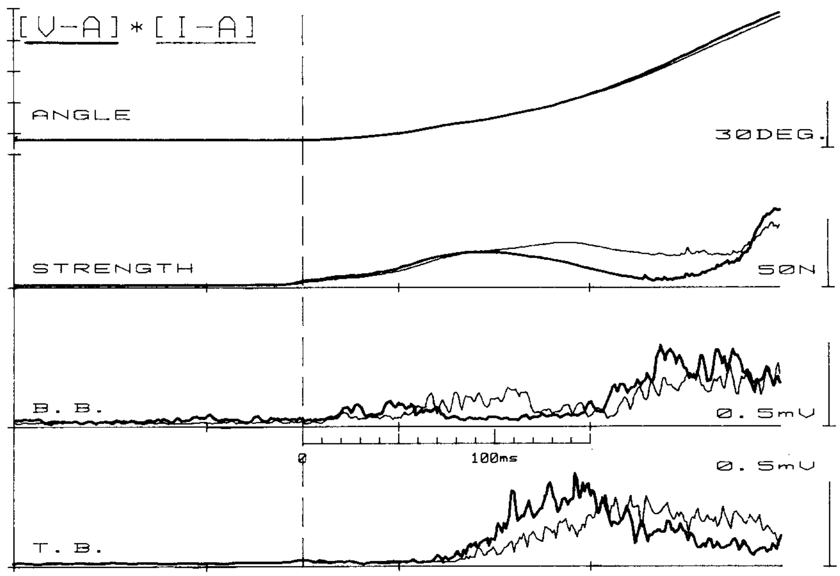

Fig. 9. The superimposed averaged curves of the conditions visible (——) and invisible (——) in the assist task of the second experimental session obtained from the typical subject. For other legends see Fig. 4

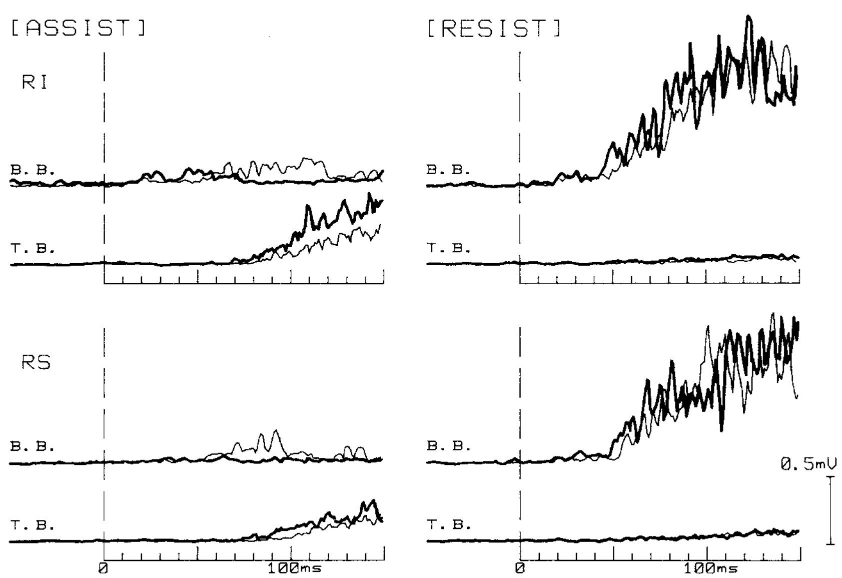

Fig. 10. The averaged EMG records superimposed for conditions visible (——) and invisible (——) in the assist and resist task of second session. The vertical broken lines indicate the stretch stimulus onset. B.B., m. biceps brachii; T.B., m. triceps brachii

between the lever arm and the subject's wrist (Fig. 1) in the present experimental apparatus, the force applied to the force transducer will decrease if the speed of elbow extension surpasses the lever arm. Therefore, the difference at 100 ms in the force record in Fig. 9 means that the elbow extension is quicker in the "visible" condition than in the "invisible" condition. The EMG activity of the elbow flexor in the "visible" condition is depressed about 70 ms after the stimulus onset and the activity of extensor begins reciprocally. In the "invisible" condition, however, EMG of the flexor does not decrease even after the extensor begins to discharge, i.e., the reciprocal activity of these two muscles is incomplete. In other words, when the visual information about the stimulus presentation is available, the distribution of motor commands to the flexors and extensors of elbow joint is regulated better and the task to extend the elbow joint is performed more efficiently than without visual information.

Figure 10 shows the averaged EMG of two visual conditions obtained from the two subjects in the second experimental session. The upper-left figurette is the same as Fig. 9. In the assist task, the EMG of biceps begins to decrease at about 50–60 ms after the stimulus onset in the "visible" condition while this is delayed until 100–120 ms in the "invisible" condition. The triceps activity

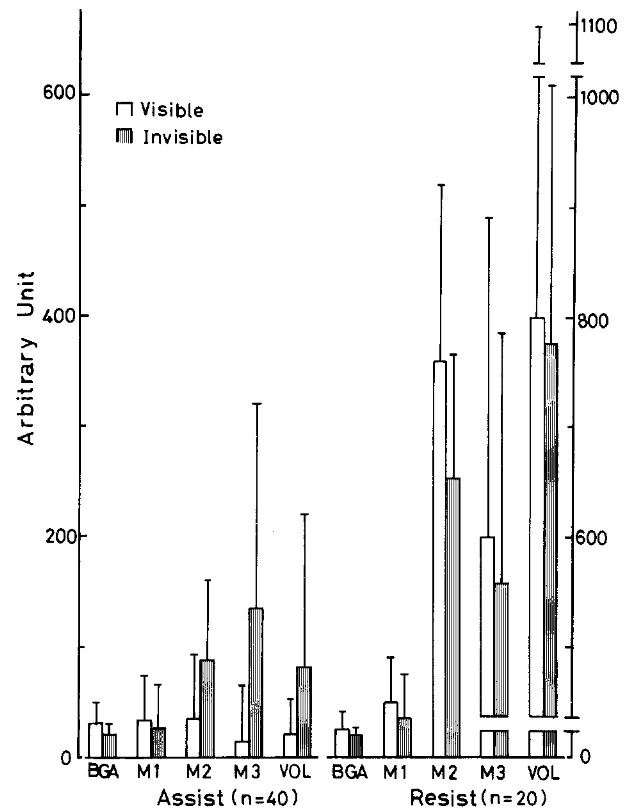

Fig. 11. The means and standard deviations of I-EMG of each integration period in the second experimental session. The scale of the right ordinate is only applicable to M3 and VOL of the resist task

begins to rise at about 70–80 ms after the stimulus in the "visible" condition while it appears at 80–100 ms in the "invisible" condition. The triceps activity in the "visible" condition is much greater than in the "invisible" condition. In the resist task, the same tendencies as the resist task of the first experimental session (see Fig. 6) were observed.

The I-EMGs of the flexor were measured in the same periods as in the first session (see Fig. 7). The means and standard deviations of I-EMG are shown in Fig. 11. In the resist task, as observed in the first sesssion (Fig. 8), the components BGA, M1 and VOL in the "visible" condition are not much larger than for the "invisible" condition, but the M2 and M3 in the "visible" condition are obviously larger than in the "invisible" condition. In the assist task, on the contrary, M2 and M3 in the "visible" condition are obviously smaller than in the "invisible" condition. Although the difference between conditions could not be statistically tested because of the small number of subjects, it could be reasonable to think that, in the assist task, M2 and M3 of biceps are more strongly depressed when the visual information about the stimulus presentation is available compared to when it is not available.

Discussion

Confirmation of the stimulus which produced the responses recorded in the present experiment

Since the subject could see, through the mirror, the hand movement of the experimenter cutting the string by the scissors in the "visible" condition, she could anticipate the time the stretch stimulus was given if she wanted to do so. Therefore, the subject might have been able to begin the task movement in time with or even prior to the actual stretch given.

If the subject had decided to begin the elbow flexion not as a response to the actual stretch stimulus but as a "timing task" timed to the stimulus onset, the onset of the EMG activity would have distributed around the onset of stretch stimulus. Consequently, the averaged EMG around the time of stretch onset in the "visible" condition in Figs. 4 ~ 6 should have been much larger than condition "invisible". In fact, the number of premature movements of the lever arm toward the subject, which would have been produced if the subject had begun elbow flexion before the stimulus was actually given, was extremely small (the mean frequency of occurrence per experiment (40 trials) was only 0.4 trials).

It was also hardly possible for the subject to react to the sound of cutting the string because of the sound produced by the scissors used was negligibly small. Even if the subject reacted to the sound of scissors, the auditory reaction time cannot be as short as 50 ms. Thus the sound could not affect the result of the present experiment.

Therefore, it could be concluded that the EMG which appeared after the stretch stimulus in the present experiment was elicited by the muscle stretch stimulus, not by the visual and auditory stimuli.

The reflex responses to the natural stretch stimulus continuously given by the gravitational force

The six subjects clearly showed the short latency two-peak response on the averaged full-wave rectified EMG. The mean latency of this response was about 15 ms, which was the same as the latencies of the spinal reflex, i.e., M1, reported previously (see Table 2). Thus, it was confirmed that not only the step torque generally used in the previous reports but also the natural gravity could induce the segmental stretch reflex.

The intense activity appeared after 50 ms latency regardless of whether a clear spinal reflex appeared or not (Fig. 6). This was identified with the activity named M2 (Table 2) judging from its latency. The separate burst corresponding to the M3 in previous reports did not appear in the present experiment but rather, the activity continued from M2 without pause. This probably resulted from the fact that the continuous stretch was applied by the free gravitational fall in the present experiment, while the brief transient step torque was applied in the previous studies listed in Table 2.

The intensity of M1 represents the activation level of the motoneuron pool at the onset of stimulus. The BGA indicates the activation level of the spinal motoneuron pool immediately before the stretch stimulus onset. Thus the BGA and M1 both represent the "readiness state" of the spinal segment around the time of stretch.

Melvill Jones and Watt (1971) reported that the subject, who was instructed to oppose as quickly as possible the maintained force suddenly applied to the foot by dorsi-flexion of the ankle joint, showed in the gastrocnemius muscle activity at about 120 ms latency. They called this activity the "functional stretch reflex (FSR)" since functionally, it plays a main role in producing the muscle strength exertion necessary to hold the ankle position. The activity of M2 which appeared 50 ms after the stretch stimulus in the present experiment also made a major contribution to the accomplishment of the resist task (Fig. 5). Therefore, M2 in the present experiment could be considered as the equivalent of the FSR in the elbow flexors.

The effect of task set – topographic preparatory set

In the present experiment, M2 and M3 components of the stretch reflex were enhanced in the resist task and depressed in the assist task. This confirms the previous reports listed in the introduction section. This kind of preparatory set is established by prior instructions given at least several seconds before the onset of stretch stimulus and can be maintained even through the whole experimental session. This long-lasting preparatory set may be called the "topographical set" in the sense that the particular muscles, topographically arranged in the human body, necessary for the task execution are specified to be prepared. We would like to propose in the following section another kind of preparatory set which plays a very important role in normal human movement.

The effect of visual information about the process of stretch stimulus presentation

Our primary interest was to investigate whether the visual information about the timing of the stretch stimulus can modulate reflex intensity. The conditions with and without visual information indeed showed clear differences in the M2 and M3 components of stretch reflex in both resist and assist tasks without showing any difference in the M1 component. These differences could be attributed to the temporal anticipation of the stretch stimulus which may be effectively established when the visual information about the process of stretch application is present.

It might be claimed that the differences in M2 and M3 between conditions are due to the mere existence of visual input to the brain. In fact, it is our common experience that mere opening of the eyelids drastically changes the base line of the EEG records since the visual input raises the arousal level of the brain. However, in this case, the depression of condition "visible" compared to "invisible" observed in the assist task, which is clearly task-related could not be explained. Therefore the between-conditional differences observed in the present experiment cannot be attributed to the mere sensory effect of the visual input.

The effect of the temporal anticipation about the time of the stimulus given was also studied by Dufossé et al. (1985). In their experiment, the unloading was applied to the elbow flexor muscle of the subject who was instructed to maintain the forearm horizontally against the load applied to the wrist. The time of the onset of unloading was previously informed by the tone signal preceding unloading by a fixed interval. This preceding signal did not reduce the activity of the elbow flexor before the unloading and could not prevent completely the elbow joint from being flexed by the unloading. But the amplitude of the "reflexive" decrease in the elbow flexor and "reflexive" increase in the elbow extensor, which was elicited by the unloading, was larger when the preceding tone signal was given in comparison with when the tone signal was not given. In the task they used, it was advantageous for good performance to reinforce this "reflexive" decrease in the elbow flexor activity. Therefore, this "reflexive" decrease in EMG amplitude was appropriately modulated when the stimulus was applied at the predictable time. This tendency in EMG corresponds well with the present observation except that they did not discriminate the components of the reflex responses.

We think that the preparatory set made up with temporal anticipation due to the visual information could not be maintained for even a few seconds. For, if this set had been maintained as long as the subject wanted, the set state of conditions with and without visual information would have been the same and no visible-invisible difference, such as that observed in the present experiment, would have been seen.

There may also be some doubts about the accuracy of anticipation about the time of stimulus onset due to the possible variability in the experimenter's movements when cutting the string. This kind of variability is unavoidable when human movements are used to present the stimulus. It may, of course, be necessary and important to manipulate nonfluctuating foreperiods in order to evaluate precisely the effect of temporal anticipation. However, the present results clearly show that there was a significant difference between the conditions "visible" and "invisible". If temporal anticipation had been totally impossible, there should have been no such clear difference between conditions.

Taking these points into consideration, we postulate that, in the normal situations, the time of onset of events, which have to be predicted for the good performance, often cannot be fixed at one particular point on the time continuum. For example, the enhancement of M2 and M3 in the biceps brachii muscle may be helpful for receiving heavy baggage, or resisting the pull of the arm in the wrestling match, and their depression in the triceps surae muscle may be good for lessening the backward sway leading to fall on the back when a skier begins to ascend a large snow hump. In these activities, the time of stretch stimulus can be predicted by visual information. But this predicted timing is very susceptible to unpredicted environmental disturbances. Moreover, human beings show a certain amount of variability in every physiological functions. Thus the humans have to use some kind of "approximate" estimation strategy to obtain efficient motor control. For this purpose, human beings have the capacity to generate, temporal preparatory sets, the highest level of which have some range of time span.

In sum, the visual information enables temporal anticipation about the movement of visual objects. In this way, "chronographic set", can contribute to the effective performance of the voluntary movement initiated by that visual object as a stimulus.

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