Journal of Physiology (1993), **469**, *pp.* 601–613
With 4 figures
Printed in Great Britain

EFFECT OF SYMPATHETIC NERVOUS SYSTEM ACTIVATION ON THE TONIC VIBRATION REFLEX IN RABBIT JAW CLOSING MUSCLES

BY C. GRASSI*, F. DERIU AND M. PASSATORE

*From the *Istituto di Fisiologia Umana, Università Cattolica del Sacro Cuore, Largo F. Vito 1, 00168 Roma and the Dipartimento di Anatomia e Fisiologia Umana, Università di Torino, Corso Raffaello 30, 10125 Torino, Italy*

(*Received 11 September 1992*)

SUMMARY

1. In precollicular decerebrate rabbits we investigated the effect of sympathetic stimulation, at frequencies within the physiological range, on the tonic vibration reflex (TVR) elicited in jaw closing muscles by small amplitude vibrations applied to the mandible (15–50 μm, 150–180 Hz). The EMG activity was recorded bilaterally from masseter muscle and the force developed by the reflex was measured through an isometric transducer connected with the mandibular symphysis.

2. Unilateral stimulation of the peripheral stump of the cervical sympathetic nerve (CSN) consistently elicited a 30–45 % reduction of the tension developed by the TVR, and a marked decrease or disappearance of the ipsilateral EMG activity. No significant changes were detected in the EMG contralateral to the stimulated nerve. Bilateral CSN stimulation reduced by 60–90 % the force reflexly produced by the jaw closing muscles and strongly decreased or suppressed EMG activity on both sides. This effect was often preceded by a transient TVR enhancement, very variable in amplitude and duration, which was concomitant with the modest increase in pulmonary ventilation induced by the sympathetic stimulation.

3. During bilateral CSN stimulation, an increase in the vibration amplitude by a factor of 1·5–2·5 was sufficient to restore the TVR reduced by sympathetic stimulation.

4. The depressant action exerted by sympathetic activation on the TVR is mediated by α-adrenergic receptors, since it was almost completely abolished by the I.V. administration of either phentolamine or prazosin, this last drug being a selective antagonist of α_1-adrenoceptors. The sympathetically induced decrease in the TVR was not mimicked by manoeuvres producing a large and sudden reduction or abolition of the blood flow to jaw muscles, such as unilateral or bilateral occlusion of the common carotid artery.

5. The effect of sympathetic stimulation was not significantly modified after denervation of the inferior dental arch and/or anaesthesia of the temporo-mandibular joint, i.e. after having reduced the afferent input from those receptors, potentially affected by CSN stimulation, which can elicit either a jaw opening reflex or a decrease in the activity of the jaw elevator muscle motoneurons.

MS 1771

6. These data suggest that, when the sympathetic nervous system is activated under physiological conditions, there is a marked depression of the stretch reflex which is independent of vasomotor changes and is probably due to a decrease in sensitivity of muscle spindle afferents.

INTRODUCTION

The existence of a direct action on muscle spindles by the sympathetic nervous system has been the subject of controversy for a long time. Opinions are divided between those who believe that the sympathetically induced modulation of spindle afferent discharge is secondary to vasomotor changes (Eldred, Schnitzlein & Buchwald, 1960) and those who believe that the sympathetic action on spindles is direct (Hunt, 1960; Hunt, Jami & Laporte, 1982; Passatore, Filippi & Grassi, 1985*a*; Passatore, Grassi & Filippi, 1985*b*; references in Staderini & Ambrogi Lorenzini, 1969). However, the differing extent of the effects observed in various muscles leaves open the question of whether or not the sympathetic action plays a significant role in motor function. Numerous studies have examined the effects of sympathetic stimulation and catecholamine administration on the stretch reflex, but unequivocal interpretation of these data is difficult since contrasting results have been obtained with different experimental conditions. In particular, intravenous administration of very large doses of catecholamines was found to produce various degrees of alternating enhancement and depression of the stretch reflex (McLennan, 1961; Francini, Peruzzi & Staderini, 1978*a*; Hodgson, Marsden & Meadows, 1969; references in Bowman, 1981), but most of these effects have been attributed to central actions of the catecholamines rather than to an effect on spindle receptors (McLennan, 1961; references in Bowman, 1981).

We reported previously that peripheral sympathetic stimulation can significantly modify the responses of muscle spindles in the jaw closing muscles of the rabbit and we provided indirect evidence that this action was not secondary to vasomotor changes. We showed that stimulation of the peripheral stump of the cervical sympathetic nerve (CSN), in anaesthetized and curarized rabbits, induces a short-latency increase in the spindle afferent discharge (Passatore *et al.* 1985*a*,*b*) with a concomitant reduction in spindle sensitivity to both static and dynamic stimuli (Passatore *et al.* 1985*b*; Grassi, Conserva & Passatore, 1989).

These data suggested that the stretch reflex evoked in masticatory muscles may be affected by physiological activation of the sympathetic system. We tested this hypothesis by investigating whether stimulation of the CSN modifies the tonic vibration reflex (TVR) in the masseter muscle, i.e. the reflex response to small amplitude vibrations applied to the mandible which predominantly activate Ia spindle afferents (Matthews, 1966, 1972; Brown, Engberg & Matthews, 1967). Some of the results presented here have been published in abstract form (Grassi, Deriu & Passatore, 1991).

METHODS

The experiments were performed on forty rabbits (weight 2·5–3·5 kg) anaesthetized with urethane (0·3 g kg^{-1}, I.V.), ketamine and xylazine (5 and 1·5 mg kg^{-1} I.V., respectively); this initial dose was supplemented, before decerebration, by continuous infusion of adequate doses of the latter two drugs through a cannulated femoral vein. Precollicular decerebration was performed,

then the forebrain rostral to the section was removed by suction. The use of a small initial dose of urethane, which is scarcely metabolized throughout the experiment, was found useful in reducing the spontaneous masticatory and body movements often occurring in decerebrate rabbits. The animal's skull was fixed in a stereotaxic frame by means of screws in the frontal bone. The CSN was isolated bilaterally and sectioned. Its peripheral stump was placed on platinum stimulating electrodes mounted inside a polyethylene cylinder (20 mm long, 2–3 mm diameter) filled with mineral oil. The cylinder was placed on a piece of blotting paper embedded with oil for further insulation. The muscles and skin of the neck were then carefully closed and stitched over the electrode cylinder assembly. The CSN was usually stimulated with 10 s^{-1} trains lasting 2–3 min (0·5 ms pulse duration, 4–8 V). Other frequencies (1–15 s^{-1}) and durations (15 s to 10 min) were also employed in some experiments. The efficacy of sympathetic stimulation was controlled throughout the experiment by observing the extent and the speed of pupillary dilatation.

The tonic vibration reflex (TVR) was elicited by vibrating the jaw muscles at 150–180 Hz, 15–50 μm peak-to-peak amplitude. For this purpose an electromagnetic vibrator (model 200, Ling Dynamic Systems, Herts) was connected to the mandibular symphysis using a screw fixed to a rigid metal extension. The displacement of the lower jaw was recorded using an inductive proximity sensor (model B18/5 OC, Selet Sensor, Torino, Italy), the steel target being fixed to the rigid extension connecting the mandible to the puller. This signal was also used for feedback control of the puller. Jaw muscle contractions were recorded through a force transducer put in series with the puller (subminiature load cell model 11, R.D.P. Electronics, Wolverhampton). This signal was low-pass filtered (5–20 Hz) to eliminate tension oscillations produced by the vibrator.

Vibratory stimulation usually lasting 5 s was repeated at intervals of 10–30 s. The trials were carried out at different values of muscle length, corresponding to 2–15 mm distance between upper and lower incisor teeth. Note that vibrations delivered at the mandibular symphysis correspond to smaller displacements of the different fibre groups of the jaw elevator muscles, depending on their insertion along the lower jaw.

Electromyographic activity from the masseter muscles of both sides was recorded either through gross 'belly-tendon' copper leads insulated except for the tip or through bipolar coaxial electrodes inserted into the muscle and slowly moved to locate EMG activity. EMG was recorded with an AC pre-preamplifier (frequency band 10 Hz–3 kHz). The EMG signals were either integrated (EMG integrator NL703 Neurolog, Digitimer, Herts), or fed into a window discriminator (model 121, WPI, New Haven, CT, USA) and counted (Instantaneous Rate NL256 Neurolog).

Heart rate was routinely monitored (ECG signal fed into a rate-meter), together with thoracic movements through an inductive proximity sensor whose target was placed on the back of the chest (model B18/5 OT, Selet Sensor). These signals indicated whether cardiac and respiratory rhythmicity changed in response to sympathetic stimulation or whether spontaneous movements occurred, as often happens in the decerebrate rabbit. Rectal temperature was maintained at 38 °C through a heating blanket controlled by a feedback circuit.

All signals were recorded on a polygraph and stored on magnetic tape for further analysis.

In seven rabbits the following drugs were administered intravenously: the α-adrenoceptor antagonists phentolamine (Regitin, Ciba; 2·0–2·5 mg kg^{-1}) and prazosin (1 mg kg^{-1}), the latter being selective for α_1-subtype, and the β-adrenoceptor antagonist, propranolol (Inderal, ICI–Pharma; 1–2 mg kg^{-1}) . In this group of animals blood pressure was measured from a cannulated femoral artery through a capacitance manometer.

We also studied the effect of sympathetic stimulation on the TVR in several control experiments, described below.

In five rabbits we used only urethane and ketamine for anaesthesia because of the reported α-adrenergic agonist action of xylazine.

In two rabbits the inferior dental arch was denervated bilaterally by crushing the inferior alveolar nerve. This was done by means of a root canal instrument (file or reamer) inserted through the dental foramen for 2·0–2·2 cm length into the horizontal part of the inferior dental canal, localized within the body of the mandible.

In two animals the temporomandibular joint was bilaterally anaesthetized by injecting xylocaine solution (1 %) just caudal to the zygomatic process of the temporal bone. The injection was lateral to the condyle (between the zygomatic process of the temporal bone and the lateral surface of the mandibular condyle) and medially to the condyle (tangent to the skull, between the skull and the medial aspect of the condyle). After entering the capsule, the neck of the mandibular ramus was reached at a depth of 7–8 mm under the skin.

In three rabbits the digastric muscle was denervated bilaterally, in one of them the central tendon of the muscle was also sectioned.

In three animals a plastic snare was placed around each common carotid artery so that they could be temporarily occluded.

At the end of the experiments the animals were killed with an intravenous injection of urethane (2 g kg^{-1}).

RESULTS

Tonic vibration reflex (TVR) in the jaw elevator muscles

In decerebrate rabbits, vibrating the lower jaw induced a TVR consisting of bilateral EMG activation with tonic contraction of the jaw closing muscles lasting as long as the mechanical stimulus was applied (Fig. 1*A*). The magnitude of the reflex response depended on the level of arousal of the animal and on the stimulus parameters. Increasing the stimulus amplitude from an initial value of 15 μm to over 100 μm progressively recruited new motor units and increased the magnitude of the reflex contraction. Increasing the frequency of the mechanical stimulus from 30 to 180 Hz and keeping the amplitude constant also increased the magnitude of the reflex tension. No significant changes in the amplitude of the reflex tension could be detected using successive 5 s trains of vibration with intervals ranging from 5 to 60 s. Vibrations lasting up to 15 min were occasionally employed and the TVR remained quite stable throughout.

In most preparations stimuli larger than 120–170 μm produced highly variable responses and often also triggered stereotyped masticatory patterns or general activation of the animal. Therefore, the majority of trials were performed by using vibrations which evoked TVR contractions ranging between 100 and 300 g, i.e. choosing the largest responses which exhibited a satisfactory stability.

Effect of cervical sympathetic nerve stimulation on the TVR

The principal effect induced on the TVR by stimulation of the peripheral stump of the CSN at 10 s^{-1} was a consistent depression of the TVR, lasting as long as the stimulus (Figs 1 and 2). This response was often preceded by a transient and variable enhancement of the reflex response and sympathetic stimulation also induced a modest increase in the baseline tension in many cases.

The initial phase of the response to sympathetic stimulation consisted of a parallel increase in both EMG activity and reflex tension in 81 % of the trials in which the CSN was bilaterally stimulated (mean increment $\pm$ S.D. was 31·2$\pm$ 24·8 % of the control value). The enhancement was smaller and less often observed with unilateral stimulation (58 % of trials; mean increment $\pm$ S.D. was 4·7 $\pm$ 15·8 %). This effect was highly variable in amplitude and duration (15–45 s) and it seemed to be related to a concomitant transient increase of breathing depth and frequency. When these effects were particularly large, they were also accompanied by a small increase in heart rate (2–7 % of the control values).

Following the initial enhancement, sympathetic stimulation produced a considerable depression of the TVR, which was observed in all trials. The initial enhancement delayed the onset of depression, which occurred within 7–15 s when the initial enhancement was absent. Bilateral CSN stimulation diminished the reflex tension by 60–90 % (mean amplitude of the response, $\pm$ S.D., was

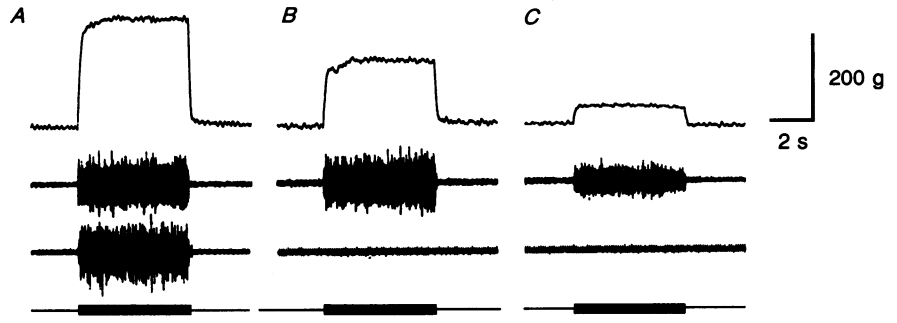

Fig. 1. Effect of CSN stimulation at 10 s^{-1} on the TVR elicited in the jaw elevator muscles of a decerebrate rabbit by vibrating the mandible. Traces show, from above, jaw muscle tension, EMG from right and left masseter muscles, and jaw displacement (redrawn). *A*, control; *B*, stimulation of the left CSN; *C*, bilateral CSN stimulation. Vibration parameters: 170 Hz, 30 μm peak-to-peak amplitude.

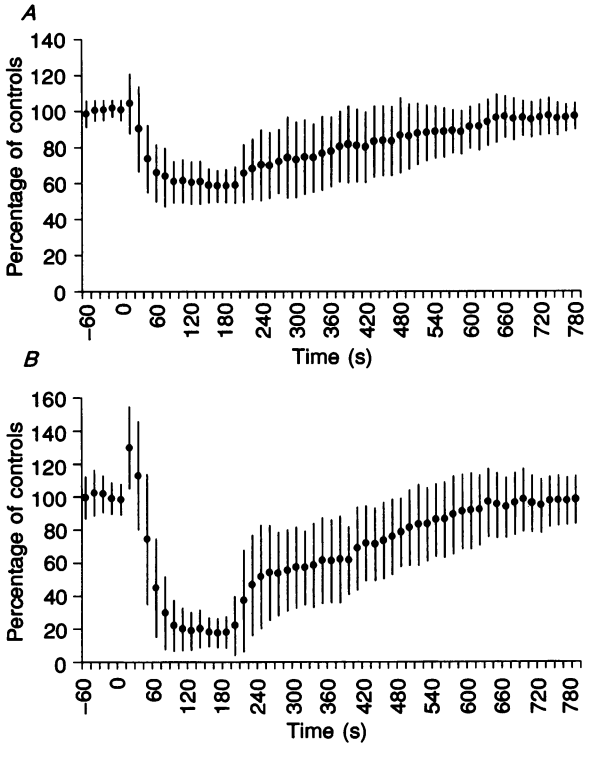

Fig. 2. Effect of unilateral (*A*) and bilateral (*B*) CSN stimulation on the TVR elicited in the decerebrate rabbits. Sympathetic stimulation at 10 s^{-1} (trains lasting 3 min) was started at time 0. Values are expressed as means $\pm$ S.D. (in *A*, $n = 40$; in *B*, $n = 48$). Vibrations lasting 5 s (170 Hz, 20–40 μm peak-to-peak amplitude, at 15 s intervals) were applied to the mandible at mouth openings corresponding to interincisal distances ranging between 2 and 4 mm.

18·7 ± 11·3 % of controls) and markedly reduced or abolished the EMG activity on both sides (Figs 1 and 2). The decrease in tension was less pronounced during unilateral CSN stimulation (mean amplitude of the reflex, ± S.D., was 58·0 ± 8·7 %). This effect was associated with a marked reduction in the number of activated

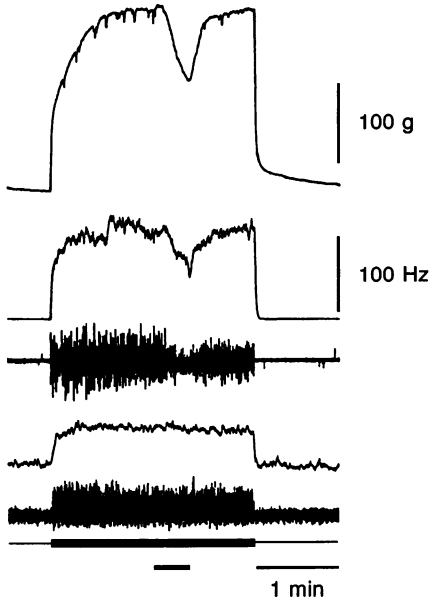

Fig. 3. Effect of right CSN stimulation at 10 s^{-1}, lasting 25 s, on a TVR elicited by a prolonged vibration of the mandible. Traces show, from above, jaw muscle tension, integrated and raw EMG from the right masseter muscle, same signals from the left masseter muscle, jaw displacement (redrawn), and right CSN stimulation (signalled by bar). Time constant of integrated signals, 500 ms. Vibration at 170 Hz, 17 μm peak-to-peak amplitude.

motor units or cancellation of the EMG activity in the masseter muscle ipsilateral to the stimulated CSN while the contralateral EMG did not exhibit significant changes. The TVR decrease developed completely within 30–110 s of stimulation and maintained its value for as long as 5 min without further decrease as long as the stimulus was maintained (Fig. 2). For longer periods of stimulation lasting 10–15 min, a partial modest recovery of the TVR amplitude was often observed, starting after 5–7 min.

After the CSN stimulation was discontinued, different motor units reflexly activated by the muscle vibratory stimuli exhibited variable returns to control, which mainly depended on the duration of sympathetic stimulation. Following long periods of stimulation, there was a rapid partial recovery within the first minute followed by a slower recovery requiring 5–10 min to completion. For shorter periods of stimulation of 1–3 min, recovery could be complete within 1 min (range, 15 s–10 min).

In the trials in which vibratory stimuli lasting 2–10 min were employed, the sympathetically induced TVR changes were very similar to those described above. Stimulation of the CSN for periods as short as 15–30 s was sufficient to reduce reflex

amplitude (Fig. 3). Under this condition a complete recovery of the TVR occurred within 10–30 s.

The percentage reduction of TVR was similar in magnitude and time course under all the conditions explored, i.e. on reflexes of different size obtained by using various vibration parameters and repeated at intervals ranging from 10 to 60 s. Also, it seemed to be similar for the whole range of jaw apertures tested (from 2 to 15 mm interincisal distance), even though a systematic study of any small changes was not performed.

The sympathetically induced depression of the TVR was also unaffected by different levels of anaesthesia with or without xylazine, or by decerebration and no anaesthesia. CSN stimulation rates below 2·5–3·0 s^{-1} did not elicit depression and increasing stimulus rates up to 6–10 s^{-1} produced responses of increasing magnitude. Further increase in stimulus rate up to 15 s^{-1} reduced the response latency and prolonged recovery time, without increasing the magnitude further.

In all trials in which unilateral CSN stimulation was performed, the EMG recorded from the non-stimulated side served to control for any changes in the mechanical stimulus or non-specific effects of the sympathetic stimulation. In all cases the EMG activity of the contralateral muscle was not significantly altered during CSN stimulation.

In addition to these effects on the vibration-induced reflex, sympathetic stimulation produced a small tonic increase in the basal tension of 10–50 g in approximately half of the trials. This effect was variable and usually lasted for only 1–2 min with continued stimulation. It was small or absent under conditions of low muscle tone. During this increase in tension a motor unit previously inactive occasionally appeared in the EMG, it discharged tonically at low frequency and was unrelated to vibration.

Possible vasomotor effects

One possible explanation of the sympathetic effects described above is that they are secondary to changes in muscle blood flow. To control for this possibility, we occluded the common carotid arteries in three animals. Unilateral and bilateral occlusions lasting 2–3 min were performed to verify whether a large sudden reduction or abolition of blood flow to jaw muscles could produce a decrease in the TVR, comparable with that induced by CSN stimulation. Instead it produced only a small and transient enhancement of both the EMG activity and reflex tension. This effect was concomitant with an increase in respiratory depth and frequency, as evaluated by recording thoracic movements. After the transient TVR increase (lasting 30–60 s), the reflex returned to control values without showing significant changes for the remaining occlusion time. Bilateral carotid artery occlusion induced qualitatively similar effects but TVR enhancement was larger and more persistent. No reduction of the TVR ever occurred in these trials. During a long-lasting (8 min) unilateral occlusion of the common carotid artery, ipsilateral CSN stimulation elicited a TVR decrease which was similar, in both extent and time course, to the effects obtained in the trials performed before blocking the blood flow to the jaw muscles. In particular, at the end of CSN stimulation TVR progressively returned to control values while the arteries remained occluded.

Other possible sympathetic effects

We checked whether some afferent inputs, possibly affected by the sympathetic stimulation, could contribute to a reduction of the TVR. To control for this possibility, we repeated the CSN stimulation trials after having denervated large

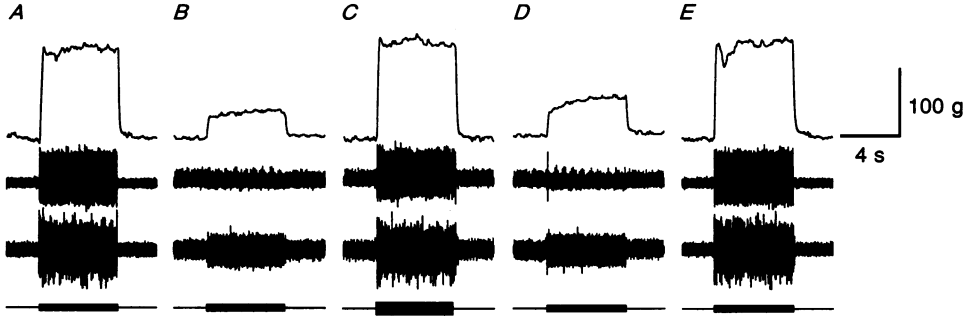

Fig. 4. Effect of increasing the vibration amplitude on the sympathetically induced depression of the TVR. Traces show, from above, jaw muscle tension, EMG from the right and left masseter muscles, and jaw displacement (redrawn). TVRs collected during control (*A*), during bilateral CSN stimulation at 10 s^{-1} (*B–D*) and 7 min after the end of sympathetic stimulation (*E*). While the TVR is depressed by CSN stimulation, an increase of the vibration amplitude from 30 to 55 μm (*C*) is needed to restore the activity in the same motor units recorded under control conditions (as evaluated in high speed records). Vibration amplitude is brought back to control values in *D*, just before the end of the CSN stimulation lasting 5 min.

areas containing receptors likely to be modified by sympathetic activation. In particular, we studied the sympathetically induced effects on the TVR in animals in which one of the following manoeuvres had been performed: (i) bilateral denervation of the inferior dental arch; (ii) bilateral denervation or section of the digastric muscle and (iii) local anaesthesia of the temporomandibular joint, bilaterally (see Methods). Data collected in all these preparations were not significantly different from those obtained in the experiments in which sensory innervation of the trigeminal area was intact.

Effect of enhancing vibration amplitude on the sympathetically induced depression of the TVR

During CSN stimulation the enhancement of the vibration amplitude could counteract the sympathetically induced depression of the TVR, increases of variable magnitude being required in the different trials. In particular, when the CSN was stimulated at 10 s^{-1}, a 1·5- to 2·5-fold increase in the vibration amplitude was sufficient on some occasions to activate the motor units whose discharge was suppressed by CSN stimulation (Fig. 4), while in others up to a 5-fold increase was insufficient. In these trials new motor units recruited by the increased stimulus amplitude could appear in the EMG record, thus making it difficult to evaluate the motor units studied. The enhancement of the stimulus amplitude also induced an

increase in the reflexly developed tension, which should be attributed both to the restoration of activity in the motor units depressed by sympathetic stimulation and to the recruitment of new motor units.

Adrenergic blockers

The sympathetically induced depression of the TVR was not affected by administration of β-adrenergic blocking agents (propranolol, 1–2 mg kg^{-1} I.V.). However, it was markedly reduced or completely abolished by α-adrenergic receptor blockade, obtained with both phentolamine (2·0–2·5 mg kg^{-1} I.V.) and prazosin (1 mg kg^{-1} I.V.). The administration of α-adrenergic antagonists did not abolish either the early enhancement of the TVR or the increase in baseline tension. Under this condition, both these effects lasted throughout the CSN stimulation instead of fading out after the first 1–2 min. This result shows that, when α-adrenoceptors have not been blocked, the sympathetically induced increases in the developed tension are usually counteracted by the larger α-adrenergic-mediated depressant action.

DISCUSSION

The results presented here show that CSN stimulation consistently decreased the TVR in the jaw elevator muscles. The effect is mediated by α-adrenergic receptors since it was almost entirely abolished by α-adrenergic blockers selective for the α_1-receptor subtype.

The depressant action of sympathetic stimulation was often preceded by a transient phase of TVR enhancement. This phase seemed to depend on the animal's level of arousal and it might be related to the increase in pulmonary ventilation that was consistently associated with this response. In fact stimulation of the CSN has been reported to increase the respiratory drive by activating carotid chemoreceptors (Heymans & Neil, 1958) and a coupling between respiratory drive and proprioceptive reflexes has also been demonstrated (Schmidt-Vanderheyden & Koepchen, 1970; Daly, 1986). The transient enhancement was scarcely affected by α_1-adrenergic antagonists implying that the mechanism responsible for the enhancement was different from that responsible for reflex suppression.

The most probable mechanism for the observed reduction in the vibration reflex, in our view, is a direct sympathetic action on jaw muscle spindle receptors. We showed in a previous study that CSN stimulation could reduce the sensitivity of spindle afferents to sinusoidal stretches of the jaw muscles in curarized rabbits (Grassi *et al.* 1989) and this could be postulated to account for the decreased reflex response. However, it must be acknowledged that there are several possible mechanisms that could be responsible for the suppression of the TVR by peripheral sympathetic stimulation. The first possibility to consider is an effect due to vasomotor changes in the jaw elevator muscles which might cause local hypoxia or mechanical changes due to adjustments in vascular filling.

Sympathetically induced vasoconstriction in rabbit skeletal muscles appears 10–15 s after the onset of sympathetic stimulation at 10 s^{-1} and develops fully about 5 s later (Öhlén, Persson, Lindbom, Gustafsson & Hedqvist, 1990). After

vasoconstriction has taken place, further time is then needed for the hypoxia to affect the various neural structures involved in the stretch reflex, as demonstrated in experiments in which blood flow had been completely interrupted (Matthews, 1933; Lloyd, 1953).

We showed that CSN stimulation for periods as short as 15–20 s, too short for the development of hypoxic conditions, can produce a decrease of the TVR. Furthermore, a reduction in local blood supply alone cannot account for the observed TVR reduction because even a total occlusion of the common carotid arteries had no effect on the TVR. Such occlusion, performed in decerebrate animals, guarantees that jaw muscles do not receive blood supply (through anastomoses between internal carotid and vertebral artery systems, since the circle of Willis is interrupted) while the brainstem reflex pathways underlying the TVR (supplied by the vertebral arteries) should not be affected. The fact that arterial occlusion caused neither a change in the vibration reflex, nor a modification of the CSN stimulation effect implies that the sympathetic effects are not mediated by blood flow-induced changes in muscle mechanics or by local hypoxia.

Another possibility to consider is an action by catecholamines to decrease jaw muscle contraction. However, in previous studies we showed that CSN stimulation consistently increased rather than decreased the contractile force of directly stimulated jaw muscle (Passatore & Grassi, 1989, 1991).

The possibility that the sympathetic action is exerted at the level of the spindle receptor is supported by both morphological and functional data. Anatomical findings are available in the literature showing that noradrenergic axons, reportedly unrelated to blood vessels, innervate muscle spindles (Santini & Ibata, 1971; Barker & Saito, 1981; Barker & Saed, 1987). Stimulation of the lumbar sympathetic trunk has been reported to reduce the response of spindle afferents to both fusimotor stimulation and muscle stretch, in the cat gastrocnemius muscle (Hunt, 1960). A direct action exerted by adrenergic terminals on muscle spindles has been also suggested as the mediator of the reduction in both phasic stretch reflex and TVR observed in cat hindlimb muscles following sympathetic stimulation and adrenaline administration (Francini *et al.* 1978*a*, *b*).

Our preliminary data on the effect of CSN stimulation on the sensitivity of jaw muscle spindles in non-decerebrate rabbits showed that spindle responses to 1 mm amplitude sinusoidal muscle stretch at 1 Hz were reduced by as much as 40 % (Grassi *et al.* 1989). Further studies of spindle responses, performed on decerebrate rabbits, are still needed to confirm whether sympathetic stimulation can have a similar marked effect on the spindle responses to high frequency vibration. Nevertheless, the data presented here, showing that an increase of the vibration amplitude can restore the TVR depressed by sympathetic fibre activation, are consistent with a reduction of spindle sensitivity by sympathetic action.

We also considered the possibility that afferent information from other receptors, which might have been modulated by the sympathetic stimulation, can contribute to the sympathetically induced TVR decrease through either a reflex activation of the jaw depressor muscles or a decrease of activity in the jaw elevator muscle motoneurons. Numerous reports have indicated that catecholamines can modulate

the activity of several somatic and visceral afferent inputs, and effects of opposite sign have been reported for different receptors (references in Akoev, 1981, and in Passatore & Grassi, 1989). In particular, various receptors in the teeth and periodontal structures are modulated by sympathetic stimulation (Matthews, 1976; Cash & Linden, 1982; Passatore & Filippi, 1983; Aars, Brodin & Bjørnland, 1988) and the existence of sympathetic fibres innervating the temporomandibular joint has been recently reported (Widenfalk & Wiberg, 1990). It has also been reported (Shyu, Olausson, Huang, Widerström & Andersson, 1989) that sensory information carried by certain populations of C fibres is reduced by activation of the sympathetic system, due to an action exerted on impulse transmission in the peripheral nerve. However, this effect seems to be limited to C fibres and is therefore unlikely to play a role in the reduction of proprioceptive reflexes.

We analysed the sympathetic effects on the TVR after reducing the afferent input from receptors which could elicit either a jaw-opening reflex or a decrease in the activity of the jaw elevator muscle motoneurons. Following denervation of the inferior dental arch and/or anaesthesia of the temporomandibular joints, there was no change in the sympathetic action on the TVR. Although the receptors from teeth and periodontal structures were not completely denervated (only those from the inferior dental arch were destroyed) and a complete denervation of the temporomandibular joint receptors could not be verified, the absence of any detectable changes in the CSN effects after these procedures suggests that sensory input from these structures does not play a role in the observed TVR reduction. It is also unlikely that tendon organs had any role in the effect since both anatomical (Barker & Saito, 1981) and functional (Hunt, 1960) studies have denied the existence of sympathetic innervation of tendon organ receptors. In any case, the TVR decrease was unaffected by bilateral section of the digastric muscle, which would be reflexly activated by an increase of the discharge frequency in all the receptors considered above. Contraction of this muscle could in fact partially counteract the TVR in jaw elevator muscles. Thus it seems highly improbable that sympathetically modulated afferent inputs other than spindles, coming from the territory innervated by the CSN, contribute significantly to the sympathetically induced reduction of the TVR.

Sympathetic action on the TVR has been observed with stimulation frequencies which match the sympathetic activity reported under physiological conditions (Polosa, 1979; references in Janig, 1985). In particular, the spectral analysis performed on background discharge of sympathetic nerves supplying various territories shows that the power in all nerves is between 0 and 15 Hz, the major component being between 2 and 6 Hz (Kocsis, Gebber, Barman & Kenney, 1990). Then, assuming that the sympathetic activity responsible for the depressant action exerted on TVR uses frequencies in the same range, it should be expected that such an action is operating under physiological conditions.

The authors wish to express their gratitude to Dr R. E. Poppele for his helpful criticism on the manuscript. The assistance of Mrs Luisella Milano is gratefully acknowledged. This work was supported by grants from the Consiglio Nationale delle Richerche and from the Ministero dell'Univerità e della Ricerca Scientifica e Tecnologica.

REFERENCES

AARS, H., BRODIN, P. & BJØRNLAND, T. (1988). Sympathetic modulation of the jaw opening reflex in anaesthetized rabbit. *Acta Physiologica Scandinavica* **134**, 319–325.

AKOEV, G. N. (1981). Catecholamines, acetylcholine and excitability of mechanoreceptors. *Progress in Neurobiology* **15**, 269–294.

BARKER, D. & SAED, H. H. (1987). Adrenergic innervation of rat jaw muscles. *Journal of Physiology* **391**, 114*P*.

BARKER, D. & SAITO, M. (1981). Autonomic innervation of receptors and muscle fibres in cat skeletal muscle. *Proceedings of the Royal Society* B **212**, 317–332.

BOWMAN, W. C. (1981). Effects of adrenergic activators and inhibitors on the skeletal muscles. In *Handbook of Experimental Pharmacology*, vol. 54, *Adrenergic Activators and Inhibitors*, section 2, ed. SZEKERES, L., pp. 47–128. Springer, Berlin, Heidelberg, New York.

BROWN, M. C., ENGBERG, I. & MATTHEWS, P. B. C. (1967). The relative sensitivity to vibration of muscle receptors in the cat. *Journal of Physiology* **192**, 773–800.

CASH, R. M. & LINDEN, R. W. A. (1982). Effects of sympathetic nerve stimulation on intra-oral mechanoreceptor activity in the cat. *Journal of Physiology* **329**, 451–463.

DALY, M. DE B. (1986). Interaction between respiration and circulation. In *Handbook of Physiology*, section 3, *The Respiratory System*, vol. II, *Control of Breathing*, part I, ed. CHERNIACK, N. S. & WIDDICOMBE, J. G., pp. 559–562, American Physiological Society, Bethesda, MD, USA.

ELDRED, E., SCHNITZLEIN, H. N. & BUCHWALD, J. (1960). Response of muscle spindles to stimulation of the sympathetic trunk. *Experimental Neurology* **2**, 13–25.

FRANCINI, F., PERUZZI, P. & STADERINI, G. (1978*a*). Effects of sympathetic catecholamines (adrenaline and noradrenaline), injected intra-arterially on the myotatic reflex activity of the quadriceps muscle in decerebrate cat. *Bollettino della Società Italiana di Biologia Sperimentale* **54**, 1331–1333.

FRANCINI, F., PERUZZI, P. & STADERINI, G. (1978*b*). Effects of the lumbar sympathetic trunk stimulation on the tonic vibration reflex (TVR) of the ankle extensor muscles in decerebrate cat. *Bollettino della Società Italiana di Biologia Sperimentale* **54**, 1339–1341.

GRASSI, C., CONSERVA, E. & PASSATORE, M. (1989). Action of the sympathetic system on gain and phase of the spindle afferent response to sinusoidal changes of length. *Pflügers Archiv* **415**, S14.

GRASSI, C., DERIU, F. & PASSATORE, M. (1991). Effects of sympathetic nervous system activation on the tonic vibration reflex in jaw-closing muscles of the anaesthetized rabbit. *Journal of Physiology* **435**, 59*P*.

HEYMANS, C. & NEIL, E. (1958). *Reflexogenic Areas of The Cardiovascular System*. Churchill, London.

HODGSON, H. J. F., MARSDEN, C. D. & MEADOWS, J. C. (1969). The effect of adrenaline on the response to muscle vibration in man. *Journal of Physiology* **202**, 98*P*.

HUNT, C. C. (1960). The effect of sympathetic stimulation on mammalian muscle spindles. *Journal of Physiology* **151**, 332–341.

HUNT, C. C., JAMI, L. & LAPORTE, Y. (1982). Effects of stimulating the lumbar sympathetic trunk on cat hindlimb muscle spindles. *Archives Italiennes de Biologie* **120**, 371–384.

JANIG, W. (1985). Organization of the lumbar sympathetic outflow to skeletal muscle and skin of the cat hindlimb and tail. *Reviews of Physiology, Biochemistry and Pharmacology* **102**, 119–213.

KOCSIS, B., GEBBER, G. L., BARMAN, S. M. & KENNEY, M. J. (1990). Relationships between activity of sympathetic nerve pairs – phase and coherence. *American Journal of Physiology* **259**, R549–560.

LLOYD, C. D. P. (1953). Influence of asphyxia upon the responses of spinal motoneurons. *Journal of General Physiology* **36**, 673–702.

MCLENNAN, H. (1961). The effect of some catecholamines upon a monosynaptic reflex pathway in the spinal cord. *Journal of Physiology* **158**, 411–425.

MATTHEWS, B. (1976). Effect of sympathetic stimulation on the response of intradental nerves to chemical stimulation of dentine. In *Advances in Pain Research and Therapy*, ed. BONICA, J. J., LIEBESKIND, J. C. & ALBE-FESSARD, D. G., pp. 195–203. Raven Press, New York.

MATTHEWS, B. H. C. (1933). Nerve endings in mammalian muscle. *Journal of Physiology* **78**, 1–53.

MATTHEWS, P. B. C. (1966). The reflex excitation of the soleus muscles of the decerebrate cat caused by vibration applied to its tendon. *Journal of Physiology* **184**, 450–472.

MATTHEWS, P. B. C. (1972). *Mammalian Muscle Receptors and their Central Actions.* Monographs of the Physiological Society. Edward Arnold, London.

ÖHLÉN, A., PERSSON, M. G., LINDBOM, L., GUSTAFSSON, L. E. & HEDQVIST, P. (1990). Nerve-induced nonadrenergic vasoconstriction and vasodilatation in skeletal muscle. *American Journal of Physiology* **258**, H1334–1338.

PASSATORE, M. & FILIPPI, G. M. (1983). Sympathetic modulation of periodontal mechanoreceptors. *Archives Italiennes de Biologie* **121**, 55–65.

PASSATORE, M., FILIPPI, G. M. & GRASSI, C. (1985*a*). Cervical sympathetic nerve stimulation can induce an intrafusal muscle fibre contraction, in the rabbit. In *The Muscle Spindle*, ed. BOYD, I. A. & GLADDEN, M. H., pp. 221–226. Macmillan Press, London.

PASSATORE, M. & GRASSI, C. (1989). Jaw muscle reflexes can be affected by sympathetic nervous system activation. In *EMG of Jaw Reflexes in Man*, ed. VAN STEEMBERGHE, D. & DE LAAT, A., pp. 127–145. Leuven University Press, Leuven.

PASSATORE, M. & GRASSI, C. (1991). Somato-vegetative interaction at the peripheral level: possible effects on motor performance. In *Cardiorespiratory and Motor Coordination*, ed. KOEPCHEN, H. P. & HUOPANIEMI, T., pp. 181–187. Springer-Verlag, Berlin, Heidelberg, New York.

PASSATORE, M., GRASSI, C. & FILIPPI, G. M. (1985*b*). Sympathetically-induced development of tension in jaw muscles: the possible contraction of intrafusal muscle fibres. *Pflügers Archiv* **405**, 297–304.

POLOSA, C. (1979). Tonic activity on the autonomic nervous system: functions, properties, origins. In *Integrative Functions of the Autonomic Nervous System*, ed. BROOKS, McC., KOIZUMI, K. & SATO, A., pp. 342–354. University of Tokyo Press and Elsevier/North-Holland Biomedical Press, Amsterdam.

SANTINI, M. & IBATA, Y. (1971). The fine structure of thin unmyelinated axons within muscle spindles. *Brain Research* **33**, 289–302.

SCHMIDT-VANDERHEYDEN, W. & KOEPCHEN, H. P. (1970). Investigation into the fluctuations of proprioceptive reflexes in man. II. Fluctuations of the patellar tendon reflex and their relation to vegetative rhythms during controlled respiration *Pflügers Archiv* **317**, 72–83.

SHYU, B. C., OLAUSSON, B., HUANG, K. H., WIDERSTRÖM, E. & ANDERSSON, S. A. (1989). Effects of sympathetic stimulation on C-fibre responses in rabbit. *Acta Physiologica Scandinavica* **137**, 73–84.

STADERINI, G. & AMBROGI LORENZINI, C. (1969). Sympathetic nervous system and reflex muscular activity. *Archivio di Fisiologia* **67**, 70–200.

WIDENFALK, B. & WIBERG, M. (1990). Origin of sympathetic and sensory innervation of the temporo-mandibular joint. A retrograde axonal tracing study in the rat. *Neuroscience Letters* **109**, 30–35.