J. Physiol. (1987), **393**, *pp.* 135–145
With 3 text-figures
Printed in Great Britain

EFFECTS OF STIMULATION OF NASAL AND SUPERIOR LARYNGEAL INPUTS ON THE HINDLIMB VASCULATURE OF ANAESTHETIZED CATS

BY DAVID JORDAN, JULIAN F. R. PATON AND L. MICHAEL WOOD*

From the Department of Physiology, Royal Free Hospital School of Medicine, Rowland Hill Street, London NW3 2PF

(*Received 6 February 1987*)

SUMMARY

1. In chloralose-anaesthetized artificially ventilated cats, either stimulation of the nasal mucosae with water or electrical stimulation of the superior laryngeal nerve (s.l.n.) resulted in apnoea, as measured from the phrenic nerve activity, and a rise in perfusion pressure of a hindlimb perfused at constant flow. In the absence of changes in venous pressure this vascular response would indicate vasoconstriction in the hindlimb. There was, however, no significant change in either heart rate or arterial blood pressure.

2. Simultaneous stimulation of the nasal mucosae and s.l.n. also resulted in apnoea but with a larger hindlimb vasoconstriction than was obtained with stimulation of only one input. This increased vasoconstriction was not significantly different from the one which in theory could be obtained by summing the two individual responses from stimulation of the nasal mucosae or s.l.n.

3. In cats anaesthetized with chloralose–urethane, stimulation of the nasal mucosae or s.l.n. also evoked an apnoea and hindlimb vasoconstriction. However, in these animals this was accompanied by a bradycardia and small fall in arterial blood pressure.

4. The present results show that whilst stimulation of two parts of the upper respiratory tract evokes qualitatively similar responses in the hindlimb vasculature, simultaneous activation of the two stimuli does not appear to result in facilitation of this hindlimb vasoconstrictor response, simply an addition of those obtained on separate stimulation. The bradycardia evoked in response to upper airway stimulation is dependent on the anaesthetic used and in the present experiments could only be obtained in animals anaesthetized with choralose–urethane.

INTRODUCTION

In many species stimulation of receptors within different parts of the upper respiratory tract is known to result in qualitatively similar respiratory and cardiovascular responses (for review see Daly, 1985). In cats, dogs and monkeys stimulation of the larynx or superior laryngeal nerve (s.l.n.) results in apnoea,

* Present address: Department of Pharmacology, Smith, Kline & French Research Ltd, The Frythe, Welwyn, Herts. AL6 9AR.

bradycardia and hindlimb vasconstriction (Angell-James & Daly, 1975; Daly, Korner, Angell-James & Oliver, 1978; Daly, Litherland & Wood, 1983). The magnitude of these cardiovascular effects, i.e. the bradycardia and peripheral vasconstriction, can be altered by simultaneous activation of other reflexes. Lung inflation can partially inhibit or even reverse the effects but simultaneous stimulation of carotid body chemoreceptors can potentiate them (Angell-James & Daly, 1978; Daly *et al.* 1978).

In the dog and monkey stimulation of the nasal mucosa results in apnoea, bradycardia and peripheral vasoconstriction (Angell-James & Daly, 1972; Daly *et al.* 1978). In the cat however, Dixon & Brodie (1903) reported an apnoea and bradycardia in response to stimulation of the nasal mucosa but there have been no previous reports of the effects of such stimuli on peripheral vascular resistance.

In previous reports (Jordan & Wood, 1986, 1987) we have described the properties of a group of cells in the rostral trigeminal nuclei which receive a convergent sensory input from the nose and the s.l.n., but which were uninfluenced by tactile input from the face. Thus, in the present investigation we have examined the effect of stimulation of the nasal mucosa alone and in combination with s.l.n. stimulation on hindlimb vascular resistance in the anaesthetized cat. Some of this work has been reported briefly in abstract form (Jordan, Paton & Wood, 1986).

METHODS

A total of eleven cats (body weight 2·6–3·5 kg) were used. Five were initially anaesthetized with halothane (Fluothane, ICI) and following cannulation of the right jugular vein, α-chloralose (70 mg kg^{-1}, BDH Chemicals Ltd) was given and supplemented as necessary with 20 mg bolus doses. Four cats were anaesthetized with a mixture of α-chloralose (44 mg kg^{-1}) and urethane (Sigma Ltd, 440 mg kg^{-1}) given I.P. and supplemented with 11 mg + 110 mg bolus doses respectively as necessary. A futher two animals were anaesthetized with sodium pentobarbitone (Sagatal, May & Baker, 40 mg kg^{-1}) and supplemented with 12 mg bolus doses as necessary. In all animals the trachea was cannulated below the larynx and the animals were artifically ventilated (Harvard Apparatus Small Animal Ventilator) with air enriched with O_2, the thorax being intact. A tidal volume of 20 ml was used at a rate of 20–40 cycles min^{-1} which was adjusted to maintain arterial blood P_{CO_2} between 35 and 40 mmHg. The pH of the arterial blood was kept between 7·35 and 7·40 by I.V. bolus injections of molar sodium bicarbonate. All blood gas variables were measured using a Corning Blood Gas Analyzer (Model 158) at frequent intervals throughout the experiment. Two side arms on the tracheal cannula allowed continuous monitoring of end-tidal CO_2 using an infra-red gas analyser (P. K. Morgan Ltd) and tracheal pressure. Rectal temperature was maintained between 36·5 and 38·0 °C by a heating coil placed under the animal through which warm water was circulated.

A cuffed endotracheal tube was inserted into the pharynx above the larynx and then pushed in a rostral direction into the nasopharynx where the cuff was inflated. The nasal mucosa could then be stimulated bilaterally by perfusing water through the endotracheal tube over the nasal mucosae and draining out through the nostrils. The cuff prevented water from entering the pharynx; if, however, any did appear in the mouth then the tube was repositioned, the cuff reinflated and the test repeated.

The right femoral vein and artery were cannulated for the measurement of inferior vena caval and arterial blood pressure respectively.

In those animals in which hindlimb vascular resistance was measured the following procedure, which is illustrated in Fig. 1, was used. The left common carotid artery was cannulated low in the neck and this was then used as the source of arterial blood which was pumped (Watson Marlow Pump 220) at constant flow through a heat exchanger at 38 °C to perfuse the left hindlimb via the femoral artery. Tests indicated that the output flow of this pump was constant ($\pm 5\%$) when inflow

pressure was artificially altered over the range 50–150 mmHg. The left hindlimb was vascularly isolated by tying the profunda and all other branches arising from the femoral artery for a distance of 10 mm distal to the abdominal wall. Heparin (Monoparin, Weddel Pharmaceuticals Ltd, 1500 i.u. kg^{-1}) was given I.V., supplemented with 750 i.u. kg^{-1} half-hourly, to prevent clotting of the blood, and the limb was then perfused at constant flow. Limb perfusion pressure was measured from a side-arm cannula close to the tip of the perfusion cannula. The limb perfusion pressure and

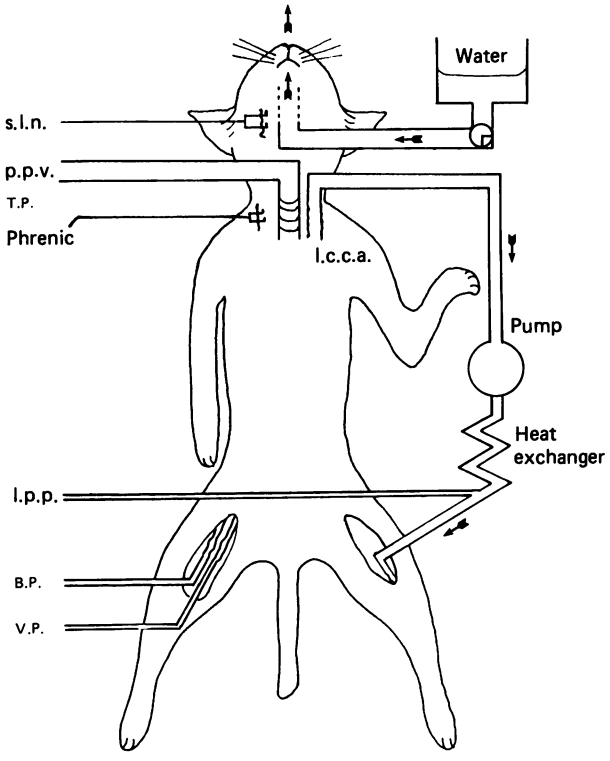

Fig. 1. Diagrammatic representation of the preparation used. A reservoir of water is connected via a tap to an endotracheal tube inserted retrogradely into the trachea and pushed into the nasopharynx. Positive pressure ventilation (p.p.v.) is applied to a tracheal cannula from which a side arm allows tracheal pressure (T.P.) to be monitored. Bipolar silver wire electrodes are used for recording phrenic nerve activity (Phrenic) and for stimulating the central end of the cut superior laryngeal nerve (s.l.n.). A cannula drains blood from the left common carotid artery (l.c.c.a.) and a constant-flow pump is used to perfuse the left hindlimb via the femoral artery, a side arm of the arterial inflow cannula being used to measure limb perfusion pressure (l.p.p.). Cannulae in the right femoral artery and vein are used to measure arterial blood pressure (B.P.) and venous pressure (V.P.).

arterial blood pressure were matched by adjusting the rate of the pump which then remained constant throughout the experiment. At the end of each experiment, vascular isolation was shown to be adequate, because on stopping the perfusion pump, the perfusion pressure fell to 13 ± 3 mmHg when systemic arterial pressure was 130 ± 14 mmHg. Thus, in the absence of changes in venous pressure, changes in limb perfusion pressure were used as an index of changes in the vascular resistance of the limb. Blood flow was measured by collecting blood for 1 min from the limb perfusion cannula. All pressures were measured using Statham P23Db pressure transducers (Statham Ltd, Puerto Rico) and conditioning amplifiers (Gould Instrument Division).

The right phrenic nerve was dissected low in the neck, the cut central end placed on bipolar silver recording electrodes and its activity differentially amplified and filtered (NL100, 104 and 125;

Neurolog Ltd). Both superior laryngeal nerves (s.l.n.) were dissected clear of connective tissue, cut close to the larynx, and placed on bipolar silver stimulating electrodes. The s.l.n.s were stimulated with square-wave pulses of 1 ms duration, 30–50 Hz and 1–10 V. The parameters were chosen to produce complete apnoea during the 30 s period of stimulation. However, it was occasionally necessary to stimulate both nerves to achieve this apnoea. Before the start of the experimental procedures the animals were paralysed with decamethonium (Sigma Ltd) (2 mg kg^{-1}) and additional decamethonium was only given after assessing the level of anaesthesia.

TABLE 1. The control values of the variables for the animals prior to the start of the tests, mean ± S.E.M.

	Chloralose ($n = 5$)	Chloralose–urethane ($n = 4$)
Arterial blood pressure (mmHg)	142 ± 8	129 ± 6
Heart rate (beats min^{-1})	176 ± 12	220 ± 8
Tracheal pressure (mmHg)	5·4 ± 0·5	5·3 ± 0·2
Phrenic rate (min^{-1})	10·2 ± 0·8	8·5 ± 1·8
Arterial blood P_{CO_2} (mmHg)	34·4 ± 2·4	38·0 ± 3·1
Arterial blood P_{O_2} (mmHg)	135·0 ± 6·0	112·7 ± 3·7
Arterial blood pH	7·402 ± 0·035	7·411 ± 0·054
Limb perfusion pressure (mmHg)	139 ± 11	
Limb blood flow (ml min^{-1})	18·5 ± 2	
Venous pressure (mmHg)	3·8 ± 0·3	

All variables were stored on magnetic tape (Racal Store 7 tape-recorder) and displayed on an electrostatic recorder (ES1000, Gould Instrument Division). Cardiovascular variables were analysed using Minitab statistical package (Pennsylvania State University) on a PDP 11/34 computer (Digital Equipment Corporation) using a paired t test. Pressure responses were measured as the peak which occurred during the test, usually 15 s after the start of the stimulus. Mean blood pressure was calculated from the diastolic pressure plus one-third of the pulse pressure. Heart rate was measured from the blood pressure signal either by counting over a 10 s period during the peak-pressure responses or continuously using a rate-meter (Royal Free Hospital medical electronics workshop). All responses were taken as being significant at the 5% level and expressed as the mean ± the standard error of the mean.

RESULTS

Table 1 shows the control data for the animals at the start of the tests. In none of the tests was there a significant change in either venous or tracheal pressure.

Animals anaesthetized with chloralose alone

Five animals were anaesthetized with chloralose and in these twenty-five tests were performed. Each test comprised three parts which were performed in random order: stimulation of the nasal mucosae, stimulation of the s.l.n., and simultaneous stimulation of the s.l.n. and the nasal mucosae. Figures 2 and 3 give examples of the responses to stimulation of the nose and s.l.n. respectively and Table 2 summarizes the data obtained. All three sets of stimuli resulted in an apnoea, as noted by absence of phrenic nerve activity, which outlasted the stimulus and an increase in hindlimb perfusion pressure indicating a vasconstriction in this vascular bed.

Limb perfusion pressure. Perfusion of the nasal mucosa with water resulted in a significant increase in limb perfusion pressure of 25 ± 2 mmHg from a control of 146 ± 4 mmHg which was maintained even when the duration of the stimulus was

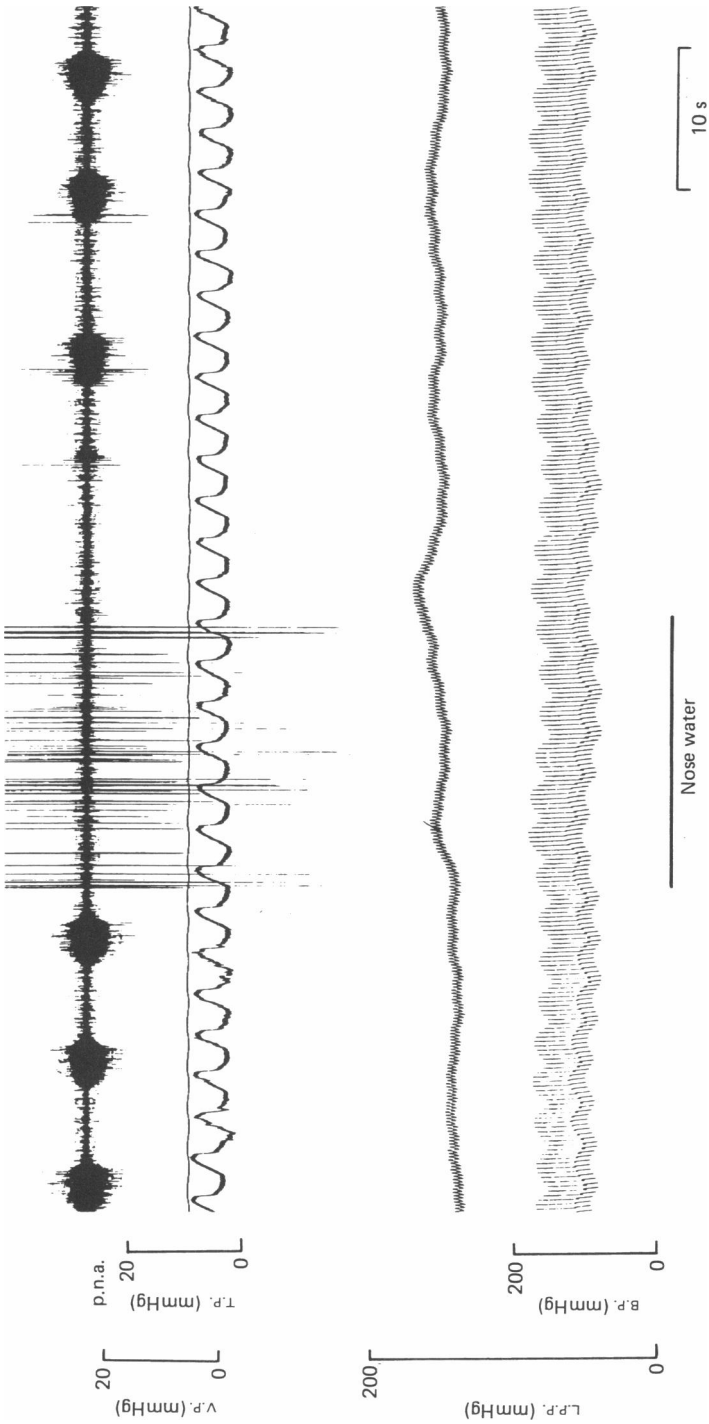

Fig. 2. α-Chloralose–anaesthetized cat. Effect of perfusing the nose with water. Records from above: p.n.a, phrenic nerve activity; V.P., venous pressure; T.P., tracheal pressure; L.P.P., limb perfusion pressure; B.P., arterial blood pressure. The interference on the phrenic nerve activity trace is an earthing artifact caused by the electrical conductivity of the water perfusion. (The animal showing neural apnoea.)

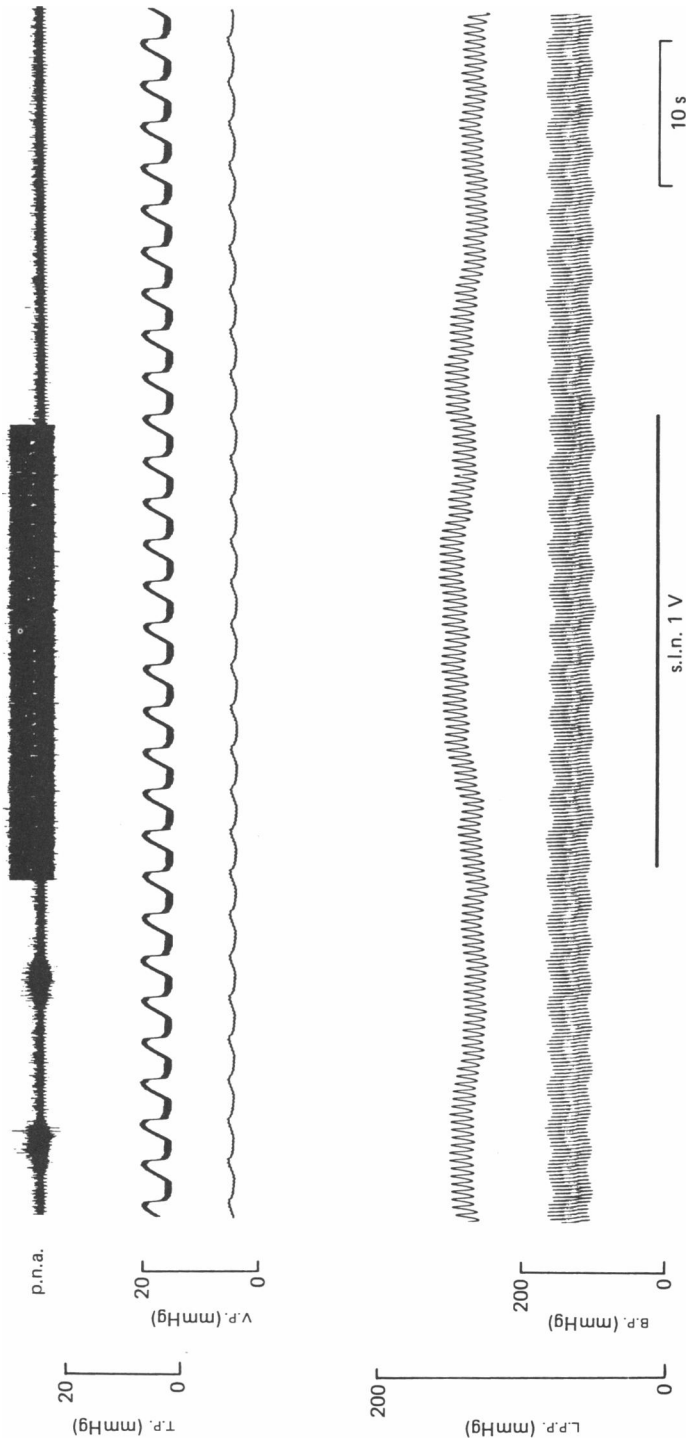

Fig. 3. α-Chloralose-anaesthetized cat. Effect of electrical stimulation of the s.l.n. (1 V, 1 ms, 30 Hz). Records from above: p.n.a., phrenic nerve activity; T.P., tracheal pressure; V.P., venous pressure; L.P.P., limb perfusion pressure; B.P., arterial blood pressure. The interference on the phrenic nerve activity trace is the stimulus artifact. (The animal showing neural apnoea.)

increased. Electrical stimulation of the s.l.n. (1–10 V, 1 ms, 30 Hz) resulted in a similar increase in limb perfusion pressure of 23±3 mmHg from a control of 146±5 mmHg. Simultaneous presentation of the two stimuli resulted in a significantly larger increase in limb perfusion pressure of 42±3 mmHg from a control of 144±4 mmHg. This increased change in limb perfusion pressure to combined stimulation of the s.l.n and nasal mucosa was not statistically different ($P > 0.28$) from the response of 48±3 mmHg which could be obtained in theory by summing the responses produced individually by the s.l.n. and the nasal mucosa.

TABLE 2. Cardiovascular responses in chloralose-anaesthetized animals. Twenty-five tests in five animals; values are mean±S.E.M.

	Arterial blood pressure (mmHg)		Heart rate (beats min^{-1})		Limb perfusion pressure (mmHg)		Phrenic rate (min^{-1})	
	Control	Response	Control	Response	Control	Response	Control	Test
			Stimulation of the nasal mucosa alone					
Mean	131	2	181	−2·5	146	25*	7·8	—
S.E.M.	4	1	5	2·6	4	2	0·4	—
			Stimulation of the s.l.n. alone					
Mean	133	3	182	0	146	23*	7·5	—
S.E.M.	4	1	5	2	5	3	0·5	—
			Simultaneous stimulation of the nasal mucosa and s.l.n.					
Mean	135	−4	184	−2	144	42*	7·4	—
S.E.M.	4	2	5	3	4	3	0·3	—

The minus sign indicates apnoea. *$P < 0.05$.

Blood pressure. Perfusion of the nasal mucosa with water or electrical stimulation of the s.l.n. resulted in small, insignificant rises in mean arterial blood pressure (Table 2) and even with combined stimulation of the s.l.n. and the nasal mucosa only a small, insignificant fall in arterial blood pressure resulted (Table 2).

Heart rate. Perfusion of the nasal mucosa, stimulation of the s.l.n. or combined stimulation of the two inputs only evoked small, inconsistent changes in heart rate (Table 2).

Animals anaesthetized with chloralose–urethane

The lack of any consistent heart rate response in the experiments described above was surprising in the light of previous work in the cat (Dixon & Brodie, 1903; Daly *et al.* 1983) in which bradycardia was found in response to upper airway stimulation. The present investigation used cats anaesthetized with chloralose alone, whereas Dixon & Brodie (1903) used ether and/or urethane and Daly *et al.* (1983) used a mixture of chloralose and urethane as their anaesthetic. It was thought possible that this difference in anaesthetic may have accounted for the discrepancy in the heart rate responses. Thus in the present series of experiments the same experimental procedure was carried out in two cats anaesthetized with a mixture of chloralose and urethane. Table 3 (A–C) summarizes this data from the four tests.

Limb perfusion pressure. Perfusion of the nasal mucosa resulted in a significant increase in limb perfusion pressure of 23±2 mmHg from a control of 196±10 mmHg whilst stimulation of the s.l.n. resulted in a smaller increase of 10±4 mmHg from a

control of 184±16 mmHg. When stimulation of the s.l.n. and the nasal mucosae were combined this resulted in a significantly greater increase in limb perfusion pressure of 32±7 mmHg from a control of 206±11 mmHg. These results are qualitatively similar to those obtained under chloralose anaesthesia.

Blood pressure. Separate stimulation of the nasal mucosa and the s.l.n. resulted in only small changes in mean arterial blood pressure (Table 3). However, combined stimulation of the s.l.n. and nasal mucosae resulted in a significant fall in arterial blood pressure of −27±8 mmHg from a control of 128±12 mmHg.

TABLE 3. Cardiovascular responses in chloralose–urethane-anaesthetized animals. Values are mean±S.E.M.

	Arterial blood Pressure (mmHg)		Heart rate (beats min^{-1})		Limb perfusion pressure (mmHg)		Phrenic rate (min^{-1})	
	Control	Response	Control	Response	Control	Response	Control	Test
	(A) Stimulation of the nasal mucosa alone							
Mean	119	0	206	−6	196	23*	5·8	—
S.E.M.	8	3	14	5	10	2	1·5	—
	(B) Stimulation of the s.l.n. alone							
Mean	121	−12*	208	−29*	184	10	6·6	—
S.E.M.	7	1	11	3	16	4	1·8	—
	(C) Simultaneous stimulation of the nasal mucosa and s.l.n.							
Mean	128	−27*	226	−27*	206	32*	7·8	—
S.E.M.	12	8	17	4	11	7	1·0	—
	(D) Stimulation of the s.l.n. alone							
Mean	123	−8*	215	−24*	—	—	8·2	—
S.E.M.	3	2	3	3	—	—	1·0	—

A, B and C, four tests in two animals. D, fourteen tests in two animals. The minus sign indicates apnoea. *$P < 0.05$.

Heart rate. In contrast to the responses recorded in animals anaesthetized with chloralose alone, in this group of animals stimulation of the nasal mucosa, s.l.n. and combined stimulation of the two inputs all resulted in bradycardia. These heart rate changes were −6·0±5·6 from a control of 206±14 beats min^{-1}, −29±3 from 208±11 beats min^{-1} and −27±4 from 226±17 beats min^{-1} respectively.

Since the heart rate and blood pressure responses to s.l.n. stimulation were different to those in the chloralose-anaesthetized animals they were also tested in another two animals in which there was no limb perfusion. In these fourteen tests again there was a significant reduction in both heart rate (−24±3 beats min^{-1} from a control of 215±3 beats min^{-1}) and arterial blood pressure (−8±2 mmHg from a control value of 123±3 mmHg) in response to s.l.n. stimulation (Table 3D).

Animals anaesthetized with sodium pentobarbitone

The heart rate and blood pressure responses to s.l.n. stimulation were also tested in two animals anaesthetized with sodium pentobarbitone. In the fourteen tests there was no significant change in heart rate (−5±5 beats min^{-1} from a control of 169±6 beats min^{-1}) or arterial blood pressure (−2±1 mmHg from a control value of 116±5 mmHg) in response to s.l.n. stimulation.

DISCUSSION

The present experiments have shown that stimulation of the nasal mucosa in the chloralose-anaesthetized cat results in a rise in hindlimb perfusion pressure. Since the limbs were perfused at constant flow and venous pressure was unaltered we take this to indicate that a vasoconstriction had occurred in the hindlimb. This is in agreement with previous studies in both dogs and monkeys (Angell-James & Daly, 1972, 1975; Daly *et al.* 1978). In addition, stimulation of the s.l.n. in the present experiments also resulted in a significant hindlimb vasoconstriction and this confirms previous reports in dogs, monkeys and cats (Angell-James & Daly, 1978; Daly *et al.* 1978, 1983). The evoked vasoconstrictions were accompanied by apnoea, as measured from a cessation in phrenic nerve activity. However, during all tests the animals were maintained with constant positive pressure ventilation and hence no part of the observed vasoconstrictions to the upper airway inputs could be due hypoxic activation of peripheral arterial chemoreceptors (Daly *et al.* 1983).

Upper airway stimulation evoked hindlimb vasoconstriction with no change in heart rate. Since there was no accompanying rise in arterial blood pressure, this must imply that resistance in at least one other vascular bed decreased in response to upper airway stimulation and this is a subject for further investigation. Whilst there was no overall significant change in mean arterial blood pressure to upper airway stimulation there was quite a range of change of pressures (from -8 to $+16$ mmHg) which might reflect such changes in resistance in other vascular beds. In addition, the small changes in arterial blood pressure make it unlikely that activation of an arterial baroreceptor reflex significantly affected the magnitude of the vascular responses we have described.

In the present experiments there was no significant change in heart rate on stimulation of the nasal mucosa, s.l.n. or combined stimulation of both in chloralose-anaesthetized cats. Whilst in the monkey Daly *et al.* (1978) also reported little change in heart rate to upper airway or s.l.n. stimulation, in the dog Angell-James & Daly (1972, 1973) reported an overall bradycardia of 31 beats min^{-1} (30%) in response to stimulation of the nasal mucosa. Similarly, s.l.n. stimulation has been reported to evoke a bradycardia in both dogs and cats (Angell-James & Daly, 1978; Daly *et al.* 1983). The present investigation and that on the monkey were carried out under chloralose anaesthesia, whereas the previous studies in the dog and cat were carried out using chloralose–urethane as the anaesthetic. In the present experiments when cats were anaesthetized with chloralose–urethane stimulation of the nasal mucosa and s.l.n. was found, as with chloralose anaesthesia, to result in apnoea and hindlimb vasoconstriction, but unlike those under chloralose anaesthesia, bradycardia was evoked during stimulation of the s.l.n. and by combined stimulation of the nasal mucosa and s.l.n. Furthermore, in animals anaesthetized with sodium pentobarbitone there was no change in heart rate in response to s.l.n. stimulation. Thus from both previous studies and the present experiments it appears that the bradycardia evoked in response to upper airway stimulation is dependent on the anaesthetic used. As far as can be determined by corneal and limb withdrawal reflexes and in the variability of cardiorespiratory parameters measured, the animals all appeared to be at similar depths of anaesthesia. One way in which this effect may

manifest itself is through a change in the baseline heart rates under the different anaesthetics. Anaesthesia with either chloralose alone or sodium pentobarbitone resulted in lower resting heart rates (176 and 169 beats min^{-1} respectively), than that under chloralose–urethane (220 beats min^{-1}). It could therefore be argued that the lower baseline values of heart rate were near to the maximum to which heart rate could be slowed by a reflex. However, in two animals under chloralose anaesthesia when the positive pressure ventilation was switched off during stimulation of the nasal mucosa or s.l.n., heart rate fell from 198 to 144 beats min^{-1} and from 198 to 126 beats min^{-1} respectively indicating that the heart could be reflexly slowed beyond the lower resting rates presumably due to arterial chemoreceptor activation.

A parallel study from this laboratory (Jordan & Wood, 1986, 1987) has reported the properties of a group of neurones within the rostral trigeminal nucleus which received a convergent sensory input from afferents in the nose and s.l.n. In that report we suggest that combined stimulation of these two parts of the upper airways might result in an interaction of the peripheral responses since the neuronal responses to combined stimulation were greater than the sum of the individual responses. However, in the present experiments this was not found to be the case in respect of hindlimb vasomotor responses since with combined stimulation of the nasal mucosa and s.l.n. a vasoconstriction equal to the sum of the individual responses to stimulation of the nasal mucosa and s.l.n. was produced. This was not the result of a saturation effect since the vasoconstrictor response to combined stimulation was not the maximum that could be produced under our experimental conditions. In two animals the positive pressure ventilation was discontinued during stimulation of the nasal mucosa and/or s.l.n. to additionally activate arterial chemoreceptors which in the cat results in peripheral vasoconstriction. Under these conditions stimulation of the nasal mucosa and s.l.n. evoked rises in limb perfusion pressure from 146 to 234 mmHg and from 150 to 230 mmHg respectively which were much greater than those achieved by combined stimulation of the nasal mucosa and s.l.n. in the ventilated animals.

In conclusion, these experiments have shown that stimulation of the nasal mucosa of the cat results in apnoea and peripheral vasoconstriction. Combined stimulation of two parts of the upper respiratory tract results in a larger constriction than that produced in response to stimulation of the individual parts but there was no evidence of a facilitatory response.

This work was supported by a Grant from the Medical Research Council. J.F.R.P. is an MRC Scholar.

REFERENCES

ANGELL-JAMES, J. E. & DALY, M. DE B. (1972). Reflex respiratory and cardiovascular effects of stimulation of receptors in the nose of the dog. *Journal of Physiology* **220**, 673–696.

ANGELL-JAMES, J. E. & DALY, M. DE B. (1973). The interaction of reflexes elicited by stimulation of carotid body chemoreceptors and receptors in the nasal mucosa affecting respiration and pulse interval in the dog. *Journal of Physiology* **229**, 133–149.

ANGELL-JAMES, J. E. & DALY, M. DE B. (1975). Some aspects of upper respiratory tract reflexes. *Acta otolaryngologica* **79**, 242–252.

ANGELL-JAMES, J. E. & DALY, M. DE B. (1978). The effects of artificial lung inflation on reflexly induced bradycardia associated with apnoea in the dog. *Journal of Physiology* **274**, 349–366.

DALY, M. DE B. (1985). Interactions between respiration and the circulation. In *Handbook of Physiology, The Respiratory System II*, ed. CHERNIACK, N. S. & WIDDICOMBE, J. G., pp. 529–594. Washington: American Physiological Society.

DALY, M. DE B., KORNER, P. I., ANGELL-JAMES, J. E. & OLIVER, J. R. (1978). Cardiovascular–respiratory reflex interactions between carotid bodies and upper-airways receptors in the monkey. *American Journal of Physiology* **234**, H293–299.

DALY, M. DE B., LITHERLAND, A. S. & WOOD, L. M. (1983). The modification of the respiratory, cardiac and vascular responses to stimulation of the carotid body chemoreceptors by a laryngeal input in the cat. *IRCS Medical Sciences* **11**, 861–862.

DIXON, W. E. & BRODIE, T. G. (1903). Contributions to the physiology of the lungs. Part I. The bronchial muscles, their innervation and the action of drugs upon them. *Journal of Physiology* **29**, 97–173.

JORDAN, D., PATON, J. F. R. & WOOD, L. M. (1986). Hind-limb vascular responses to combined stimulation of the nasal mucosa and superior laryngeal nerve in the anaesthetised cat. *Journal of Physiology* **373**, 18*P*.

JORDAN, D. & WOOD, L. M. (1986). A convergent input from the larynx and nasal mucosa of the cat. *Journal of Physiology* **372**, 23*P*.

JORDAN, D. & WOOD, L. M. (1987). A convergent input from nasal receptors and the larynx to the rostral sensory trigeminal nuclei of the cat. *Journal of Physiology* **393**, 147–155.