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Brain-mediated responses to vaginocervical stimulation in spinal cord-transected rats: role of the vagus nerves

Barry R. Komisaruk [a,*], Ralph Bianca [a], Giorgio Sansone [a], Lisbeth E. Gómez [b], Rafael Cueva-Rolón [b], Carlos Beyer [b], Beverly Whipple [c]

[a] *Institute of Animal Behavior, Rutgers, The State University of New Jersey, Newark, NJ 07102, USA*

[b] *Center for Research in Animal Reproduction (CIRA), Centro de Investigación y Estudios Avanzados, Laboratorio y Universidad Autónoma de Tlaxcala, Tlaxcala, México*

[c] *College of Nursing, Rutgers, The State University of New Jersey, Newark, NJ 07102, USA*

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Abstract

The present study was designed to ascertain whether the vagus nerves convey functional sensory activity from the reproductive tract in rats. Previously, vaginocervical mechanostimulation (VS) was shown to increase pupil diameter (PD) and the threshold of vocalization to tail shock (Voc-T). These responses were attenuated but not abolished by combined bilateral transection of the 'genito-spinal' nerves (i.e. pelvic, hypogastric and pudendal). Subsequent bilateral vagotomy further reduced or abolished the residual responses. In the present study, spinal cord transection above the known level of entry of the genito-spinal nerves was combined with bilateral vagotomy. In ovariectomized rats, after spinal cord transection at thoracic 7 (T7X), lumbar 5 (L5X) levels, or sham surgery (Sh), responses to VS were measured, the vagus nerves were then transected bilaterally, and responses to VS were again measured. VS significantly increased Voc-T and PD after sham procedure or spinal cord transection at either level. Subsequent bilateral vagotomy abolished the VS-induced increase in PD in the T7X group. Due to low survival rate, the effect of vagotomy on Voc-T could not be determined. Consequently, we performed a second experiment. In non-ovariectomized rats, VS significantly increased PD but reduced Voc-T in the T7X group compared to the Sh group, and subsequent bilateral vagotomy abolished both responses. These findings provide evidence that, in the rat, the vagus nerves provide a functional sensory pathway from the reproductive tract directly to the medulla oblongata of the brain, bypassing the spinal cord.

Keywords: Vagus nerve; Spinal cord; Vagina; Cervix; Vaginocervical stimulation; Analgesia; Pupil dilatation

1. Introduction

There is recent evidence that the vagus nerves convey significant afferent activity from the reproductive tract directly to the brain. A previous study from this laboratory had shown that combined pelvic and hypogastric neurectomy, while significantly reducing certain responses to VS, did not abolish them [6]. In more recent findings from this laboratory, bilateral vagotomy was found to abolish the VS-induced analgesia and pupil dilatation that persisted after complete deafferentation of all the spinal sensory nerves known to innervate vagina, cervix and uterus in the rat [5].

Transection of the vagus nerves has been reported to block vaginocervical stimulation-produced pseudopregnancy, deciduoma formation, and an increase in plasma levels of prolactin and progesterone that are associated with pseudopregnancy [2,4]. Furthermore, injection of horseradish peroxidase into cervix and uterus labeled vagal sensory cell bodies in the nodose ganglion [14], providing neuroanatomical evidence that, in the rat, the vagus nerves contain afferents from cervix and uterus.

In the present study, we utilized spinal cord transection rather than nerve transection in order to block genito-spinal afferent activity to the brain. Thus, we transected the spinal cord at the thoracic (T7) level, i.e. above the reported levels of entry of all the known genito-spinal nerves [15,16,21], while leaving intact the vagus nerves, which bypass the spinal cord and enter the medulla oblongata directly.

This animal model was developed to help account for the finding from this laboratory that women who have been diagnosed as having 'complete' spinal cord injury (at spinal cord levels varying between T6 and L2) experience

* Corresponding author. Fax: (1) (201) 648-1102.

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perceptual responses to vaginal and/or cervical self-stimulation, including an increase in pain threshold (measured at the fingers) to vaginal or cervical self-stimulation, in addition to experiencing menstrual cramps and sexual responses including orgasm [11,24]. A preliminary report of the present findings has been published in abstract form [1].

2. Materials and methods

2.1. Subjects

Subjects were female Sprague-Dawley rats weighing 250–300 g. They were housed at 23°C, and maintained on a reversed-light cycle (lights off at 10.00 h, on at 22.00 h). Food and water were supplied ad libitum.

2.2. Experimental design

Fig. 1 depicts, in schematic form, the rationale for the present study. In one group, spinal cord transection was performed at the T7 level to determine whether this would replicate the effects reported after transection of the pelvic, hypogastric and pudendal nerves [5]. In another group, spinal cord transection was performed at the L5 level, leaving intact the input from the hypogastric nerve to the brain that enters the spinal cord at T13–L4 [21] (the other components of the hypogastric nerve enter the spinal cord at L6–S2 [21]). It was anticipated that rats in the L5 spinal cord-transection group would provide a greater response to VS than those in the T7-transected group. After spinal cord transection, bilateral vagotomy was performed to determine which, if any, of the residual responses to VS was affected. In Expt. 1, all subjects underwent ovariectomy followed by spinal cord transection at T7 (T7X) or L5 (L5X), or a sham operation (Sh). Behavioral testing (i.e. effects of VS on vocalization threshold and pupil diameter) was conducted after a 7-day recovery period. Subsequent to testing, each group was divided such that one subgroup received subdiaphragmatic bilateral vagotomy (VX) and a second subgroup received a sham operation (Sh). Behavioral testing was repeated after recovery. Expt. 2 was similar to Expt. 1, except that subjects did not undergo ovariectomy and all surgical procedures were performed in a single session.

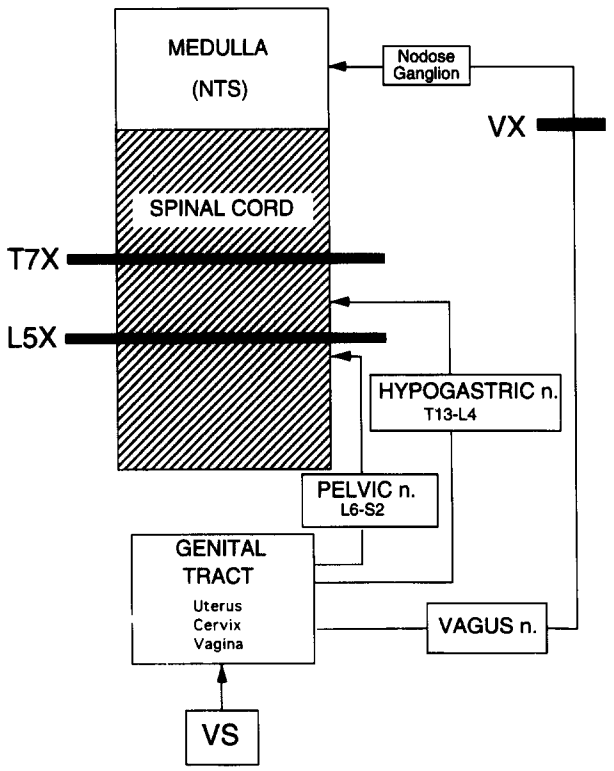

Fig. 1. Schematic diagram of the rationale for the present study. In Expt. 1, spinal cord transection was performed at L5 or T7 and the rats were tested for residual responses to VS (i.e. analgesia and pupil dilatation). Subsequently, bilateral transection of the vagus nerves at the subdiaphragmatic level was performed to determine which, if any, of the residual responses were affected. In Expt. 2, spinal cord transection at T7 and bilateral neurectomy of the vagus nerves at the subdiaphragmatic level were performed simultaneously and behavioral tests were performed subsequently.

Group abbreviations: multiple treatments are depicted with '+'; e.g., the group that received T7 spinal cord transection followed by vagotomy is designated as T7X + VX, and the group that received sham spinal cord transection followed by sham vagotomy is designated as Sh + Sh, etc.

2.3. Surgical procedures

2.3.1. Spinal cord transection

Using a Zeiss surgical microscope and pentobarbital anesthesia (4.5 mg/100 g b.wt.), the intervertebral space between vertebrae T5 and T6, or T13 and L1, was visualized in order to expose the T7 and L5 levels of the spinal cord, respectively, according to the anatomical schema of Hebel and Stromberg [10]. The spinal cord was transected at either site with the use of microscissors. The microscissors were angled rostrad then caudad, thus making two cuts approx 5 mm apart. Then the segment of spinal cord was completely removed under surgical microscopic control via aspiration pump using 18- and 23-gauge blunted hypodermic needles. The cavity was packed with Gelfoam to control bleeding, after which the overlying muscle and skin were sutured, and the rats were placed on a heating pad with rectal thermal sensor (Harvard Animal Blanket Control Unit; Harvard Apparatus, Edenbridge, Kent, UK) for several hours post-surgery in order to stabilize their core temperature. The sham operation consisted of spreading apart the T5 and T6, or T13 and L1 vertebrae, to reveal the spinal cord at either T7 or L5, respectively, cutting the dura mater to expose but not cut the spinal cord, and then suturing the overlying muscle and skin.

2.3.2. Subdiaphragmatic vagotomy

Prior to surgery, the rats were food-deprived overnight to reduce stomach volume. Under surgical microscopic control and pentobarbital anesthesia, the abdominal cavity was opened by a midline incision. The liver was gently reflected to the rat's right side and the esophageal-stomatic junction was located as a landmark [9]. The stomach and esophagus were gently retracted caudad with the use of a blunt hook placed around the junction. Both the anterior and posterior vagal trunks, lying along the esophagus, were visualized and transected. Sham vagotomy consisted of exposing and gently retracting the stomach and esophagus to visualize both vagus nerve trunks. The muscle and skin surrounding the incision were then sutured.

2.3.3. Vaginocervical mechanostimulation (VS)

Mechanical probing (500 *g* force) was applied against the cervix using a force-calibrated dynamometer (Wagner Instruments, Model FD 500, Greenwich, CT) that was modified to accept a probe tipped with a rubber stopper from a 1 cc plastic syringe plunger. The force of probing was intended to maximize responses to VS.

2.3.4. Daily postsurgical care

In order to maintain the subjects in healthy condition after spinal cord transection, daily washing of the ventrum with warm running water, towel drying, and twice-daily manual expression of urine were administered. Oxytetracycline (17 mg/kg b.wt.) and gentamicin sulfate (5 mg/kg b.wt.) were given i.m. twice daily to prevent infections of the urinary tract. After spinal cord transection, and for the remainder of the experiment, estradiol benzoate (100 μg/kg b.wt., s.c.) was injected daily to maximize responses to VS. After vagotomy, atropine sulfate (0.1 mg/kg b.wt.) and theophylline (8 mg/kg b.wt.) were administered i.p. twice daily to reduce fluid accumulation in the respiratory tract. Atropine therapy was used only in Expt. 2. On the day of testing, atropine therapy was withheld until after testing was completed. All rats were maintained in an incubator at 25°C and 60% humidity. At the end of the experiment, all rats were euthanized with an overdose of pentobarbital (65 mg in 1 ml, i.p.).

2.4. Behavioral testing

After approx. 7 days post-surgical recovery, the rats were tested for VS-induced responses, using blind procedures. Each rat was wrapped gently in cloth bunting and was given a 5-min period to acclimate prior to the onset of testing. The following tests were administered.

2.4.1. Vocalization threshold (Voc-T)

Two 0.25 mm diameter silver wire electrodes were inserted via a 20-gauge trochanter, approx 1.5 cm apart, intradermally in the upper forelimb. Electrical current (100 ms-duration train of 60 Hz sine waves) was delivered to the forelimb at 3 s intervals using a Coulbourn Instruments Programmable Shocker (Lehigh Valley Electronics, Allentown, PA). Computer-generated stepwise increments (0.03 μA) in intensity of current were applied until vocalization was elicited. The current was then reduced until it no longer produced vocalization, and then increased stepwise again until vocalization was again elicited. This procedure was repeated for a total of 3 ascending and 3 descending inversions. The average of the current at the 6 inversions was taken as the vocalization threshold.

2.4.2. Pupil diameter (PD)

The reticle of the surgical microscope was calibrated at a fixed magnification (25 ×). The pupil of each subject was visualized and its diameter measured at the focal point (13 units = 1 mm). A constant dim illumination was main-

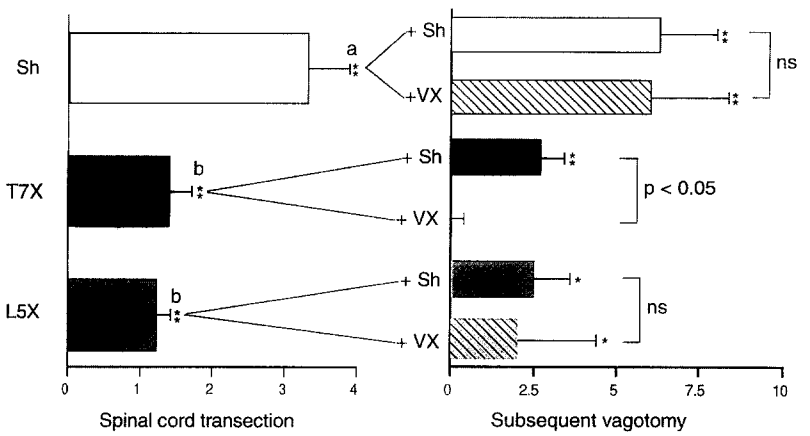

Fig. 2. Absolute magnitude of change in pupil diameter to VS (13 units = 1 mm) pre- to during-VS, in Expt. 1. Pupil dilatation in response to VS persisted after complete spinal cord transection at T7 or L5. Subsequent bilateral vagotomy abolished this effect only in the T7-transected rats (the hypogastric nerve input to the brain enters the spinal cord above L5). ** Significant within-group increase over baseline ($P < 0.01$, Scheffé test). * Significant within-group increase over baseline ($P < 0.05$, Scheffé test). ab Groups with different letters differ significantly from each other ($P < 0.01$, Tukey's protected *t*-test); *n*'s: Sh = 10, T7X = 10, L5X = 10.

tained in the experimental room. In addition, a rheostat was used for the light source of the surgical microscope, in order to obtain a baseline approx half-maximum pupil diameter, that was maintained for the entire testing period. In each experiment, after each surgical treatment, all the rats in the experimental and control groups were tested for pupil dilatation on the same day and under the same lighting conditions.

2.4.3. Statistical analysis

All values are expressed as mean ± S.E.M. Comparisons among different groups (mean absolute change or percent change from baseline) were made using one-way analysis of variance (ANOVA). Multiple *t*-tests with Bonferroni correction or a two-way ANOVA (3 × 2 design, [surgery × stimulus] with repeated measures for stimulus), were performed in order to compare differences among surgical treatment groups and for pre-VS versus during-VS conditions. Post hoc comparisons were performed using Scheffé's or Turkey's protected *t*-tests. All P values are reported as 2-tailed; a level of $P \leq 0.05$ was considered statistically significant.

3. Results

3.1. Experiment 1: spinal cord transection and subsequent vagotomy

3.1.1. Spinal cord transection

3.1.1.1. Pupil diameter (PD). Spinal cord transection significantly reduced the magnitude of pupil dilatation in response to VS in both the L5X and T7X groups compared to the Sh control group (1-way ANOVA: $F_{2,12} = 16.77$, $P < 0.001$; Tukey's protected *t*-tests, all P's < 0.01) (Fig. 2, left side). The difference in magnitude of the VS-produced pupil dilatation between the L5X and T7X groups was not significant ($P > 0.05$, Tukey's). Nevertheless, VS significantly elevated pupil diameter above pre-VS baseline values in each of the L5X, T7X and Sh groups (2-way ANOVA: $F_{2,36} = 8.59$, $P < 0.001$; Scheffé comparisons, all P's < 0.01).

3.1.1.2. Vocalization threshold (Voc-T). Spinal cord transection significantly reduced the magnitude of the increase in Voc-T in response to VS in both the L5X and T7X groups compared to the Sh control group (1-way ANOVA: $F_{2,30} = 7.19$, $P < 0.003$; Scheffé comparisons, all P's < 0.01) (Fig. 3). The L5X and T7X groups did not differ significantly from each other. Despite this significant reduction, VS continued to produce a significant increase in Voc-T compared to the pre-VS condition in each of the L5, T7 and Sh groups (2-way ANOVA: $F_{2,36} = 10.89$, $P < 0.0002$; Scheffé comparisons, all P's < 0.01).

3.1.2. Subsequent vagotomy

3.1.2.1. Pupil diameter. Post-vagotomy (VX) results are based on the surviving rats in 6 groups, i.e. Sh + Sh ($n = 3$), Sh + VX ($n = 4$), T7X + Sh ($n = 3$), T7X + VX ($n = 3$), L5X + Sh ($n = 3$) and L5X + VX ($n = 4$). As shown in Fig. 2 (right side), vagotomy abolished the PD response to VS in the T7X + VX group in contrast to the T7X + Sh group ($P < 0.05$, multiple *t*-tests; pairwise comparisons). In all groups except T7X + VX, VS produced a significant increase in PD over baseline (pre-VS) values (2-way ANOVA: $F_{5,18} = 3.39$, $P = 0.02$; Scheffé comparisons, all P's < 0.05). There was no significant difference in the magnitude of pupil dilatation in response to VS between the L5X + VX and L5X + Sh groups. Bilateral vagotomy-only, in spinal cord-intact rats (i.e. Sh + VX), did not significantly affect pupil dilatation in response to VS. In the three groups of sham-vagotomized rats, combined, the magnitude of the pupil dilatation in the second phase of the experiment (Fig. 2, right side) was significantly greater than in the first phase (Fig. 2, left side) (correlated $t = 2.68$; $P = 0.03$, 2-tailed).

3.1.2.2. Vocalization threshold. The effects of vagotomy on the Voc-T response to VS could not be adequately determined after vagotomy procedure due to low survival at the time of the assessment.

3.2. Experiment 2: concurrent spinal cord transection and bilateral vagotomy

3.2.1. Pupil diameter (PD)

As shown in Fig. 4, VS produced a significant increase in PD in the Sh + Sh and T7X + Sh groups, but not in the

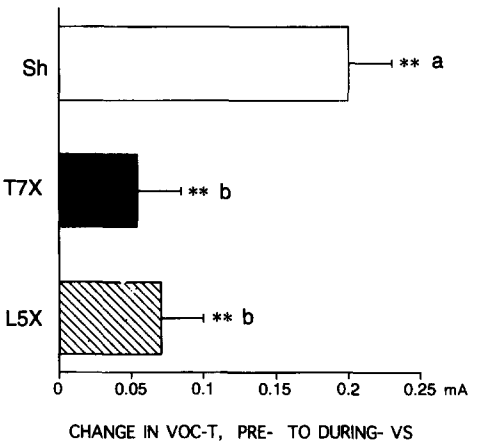

Fig. 3. Change in vocalization threshold pre- to during-VS (Expt. 1). Spinal cord transection at T7 or L5 significantly attenuated the ability of VS to elevate vocalization threshold. The effects of vagotomy plus spinal cord transection could not be assessed due to low survival rate (see results of Expt. 2). ** Significant within-group change compared to baseline ($P < 0.01$, Scheffé test). [ab] Groups with different letters differ significantly from each other ($P < 0.01$, Scheffé test). *n*'s: Sh = 10, T7X = 10, L5X = 10.

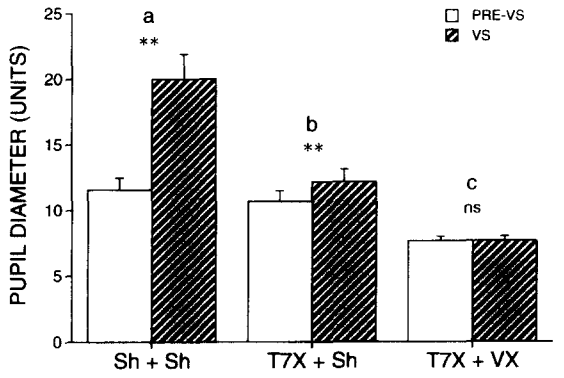

Fig. 4. VS produced pupil dilatation in the Sh + Sh and T7X + Sh groups, but not in the T7X + VX group. * * $P < 0.01$ (Scheffé test; within-group difference scores). [abc] Groups with different letters differ significantly from each other ($P < 0.01$ Scheffé test; between-group difference scores). n's: Sh + Sh = 7, T7X + Sh = 6, T7X + VX = 6.

T7X + VX group (2-way ANOVA: $F_{2,18} = 16.84$, $P < 0.0001$; significant Scheffé comparisons, all P's < 0.01). These data were analyzed as within-group change from baseline values because, based on the same ANOVA, the pre-VS pupil diameters in the Sh + Sh and the T7X + Sh groups were significantly greater than in the T7X + VX group (Sheffé comparisons, P's < 0.01). The increase in pupil diameter in the Sh + Sh group was significantly greater than that in the T7X + Sh group, and both were significantly greater than that in the T7X + VX group (1-way ANOVA: $F_{2,16} = 14.15$, $P < 0.001$; Scheffé comparisons, all P's < 0.01).

3.2.2. *Vocalization threshold (Voc-T)*

In response to VS, the mean ± s.e.m. baseline (pre-VS) vocalization thresholds (in mA) increased in the Sh + Sh group from 0.09 ± 0.01 to 0.14 ± 0.02, decreased in the

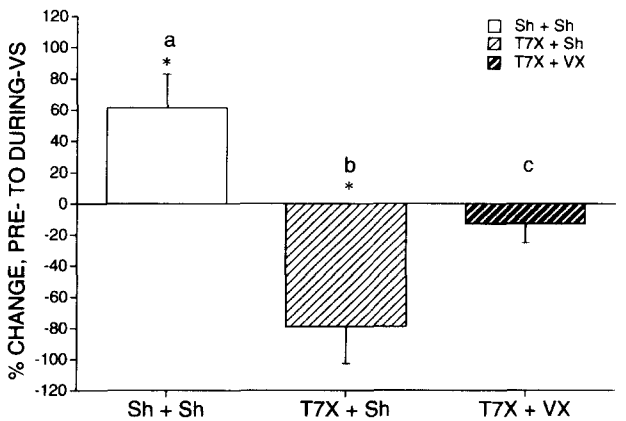

Fig. 5. The change in vocalization threshold (group mean percent change from baseline) during VS was significantly reduced in the T7X + Sh group compared to the Sh + Sh group. In the T7X + VX group, bilateral vagotomy abolished the VS-produced change in Voc-T. * $P < 0.05$ (multiple t-tests with Bonferroni correction). [abc] Groups with different letters differ significantly from each other ($P < 0.05$, Tukey's protected t-test; between-group comparisons). n's: Sh + Sh = 7, T7X + Sh = 6, T7X + VX = 6.

T7X + Sh group from 0.37 ± 0.08 to 0.13 ± 0.03, and decreased in the T7X + VX group from 0.24 ± 0.06 to 0.23 ± 0.08. Because of the variability in the baselines, the data were analyzed as percent change from baseline, and summarized in Fig. 5. As shown in Fig. 5, there was a significant difference between the change in Voc-T in the Sh + Sh group and that in the T7X + Sh group, and both these changes in Voc-T were significantly greater than that in the T7X + VX group (1-way ANOVA: $F_{2,15} = 13.64$, $P < 0.001$; Tukey's protected t tests, all P's < 0.05). VS produced a typical significant elevation in Voc-T in the Sh + Sh group ($P < 0.05$, multiple t-tests with Bonferroni correction). By contrast, VS produced a significant *decrease* in Voc-T in the T7X + Sh group ($P < 0.05$, multiple t-tests with Bonferroni correction). Voc-T showed no significant response to VS after *combined* T7X + VX (i.e. there was neither significant increase nor decrease; $P >$ 0.05, multiple t-tests with Bonferroni correction).

4. Discussion

In the present study, spinal cord transection at T7 reduced, but did not abolish, supraspinally-mediated responses to VS, i.e. pupil dilatation and alteration in vocalization threshold. Transection of the spinal cord and vagus nerves abolished pupil dilatation and vocalization threshold-elevating responses to VS. These findings are consistent with those of a previous study that analyzed the effect of genito-spinal neurectomy rather than spinal cord transection [1].

An unexpected finding in Expt. 2 was the VS-produced *decrease* in Voc-T in the T7X + Sh group, in contrast with the observed *increase* in Voc-T in a similar treatment group in Expt. 1. The difference in the direction of Voc-T in response to VS in the two experiments may be due to the use of intact, rather than ovariectomized, rats in Expt. 2. Electrical stimulation of the vagus nerve is known to produce either hyperalgesia or analgesia, depending upon the type of afferent fibers activated by the electrical stimulation [17–20]. Since the vagus nerve has been shown to innervate the ovary in the rat [3], it is possible that removal of the ovary disrupted vagal afferents and thereby produced a difference in the nature of sensory input in the two experiments.

The finding that VX abolished the PD response to VS in the T7X, but not the L5X rats, is likely due to the entry of hypogastric nerve afferents into the spinal cord above the level of the L5 transection. A previous study [6] showed that significant responses to VS persisted after bilateral pelvic neurectomy, which left the sensory input via the hypogastric nerve intact. The present finding that vagotomy-only did not significantly affect the PD response to VS indicates that the pelvic and hypogastric nerves convey the major vaginocervical afferent activity. This finding is consistent with our previous report that com-

bined bilateral pelvic and hypogastric neurectomy markedly reduced the analgesic effect of VS, whereas bilateral transection of either the pelvic or hypogastric nerves, but not both, had little or no effect [6]. These findings indicate the existence of substantial redundancy in the function of these genital afferent nerves. The greater magnitude of pupil dilatation response to VS in the second phase of Expt. 1, relative to the first phase, may have been due to a cumulative facilitatory effect of estradiol benzoate.

The present results provide evidence that sensory activity generated by vaginocervical mechano-stimulation reaches the brain via the vagus nerve, an extramedullary pathway. These findings also provide functional evidence that is consistent with: (a) neuroanatomical evidence of the existence of a uterus-brainstem pathway via the vagus nerve in the female rat [14], physiological evidence that (b) abdominal vagotomy disrupts cervical stimulation-induced pseudopregnancy, deciduoma formation, related daily prolactin surges and elevations in serum progesterone [2], and (c) evidence that oxytocin, which is necessary for normal parturition [12], is released from the posterior pituitary during parturition in high spinal cord-transected rabbits [8], and in response to electrical stimulation of the cut afferent stump of the vagus nerve [13,22], and that normal parturition occurs in paraplegic women and in spinalized dogs [7].

A genital afferent pathway to the brain via the vagus nerves, which remains functional after spinal cord transection in the rat, suggests the existence of a pathway that could account for responses to vaginal and/or cervical self-stimulation, including analgesia, menstrual cramps, and orgasm, that are reported in women diagnosed as having 'complete' spinal cord injury [11,23,24].

We conclude that in the female rat, the vagus nerves provide a functional afferent extramedullary pathway from the female genital tract directly to the brainstem, thus bypassing the spinal cord.

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References

[1] Bianca, R., Sansone, G., Cueva-Rolon, R., Gomez, L.E., Ganduglia-Pirovano, M., Beyer, C., Whipple, B. and Komisaruk, B.R., Evidence that the vagus nerve mediates a response to vaginocervical stimulation after spinal cord transection in the rat, *Soc. Neurosci. Abstr.*, 20 (1994) 961.

[2] Burden, H.W., Lawrence, I.E. Jr., Louis, T.M. and Hodson, C.A., Effects of abdominal vagotomy on the estrous cycle of the rat and the induction of pseudopregnancy, *Neuroendocrinology*, 33 (1981) 218–222.

[3] Burden, H.W., Leonard, M., Smith, C.P. and Lawrence, I.E. Jr., The sensory innervation of the ovary: a horseradish peroxidase study in the rat, *Anat. Rec.*, 207 (1983) 623–627.

[4] Chinapen, S., Nissanov, J. and Komisaruk, B.R., Densitometric analysis of the immunocytochemical labeling of fos in the nucleus of the solitary tract induced by vaginocervical stimulation, *Soc. Neurosci. Abstr.*, 20 (1994) 702.

[5] Cueva-Rolón, R., Sansone, G., Bianca, R., Gómez, L.E., Beyer, C., Whipple, B., Muñoz-Martinez, E.J. and Komisaruk, B.R., Evidence that the vagus nerve mediates some effects of vaginocervical stimulation after genital deafferentation in the rat, *Soc. Neurosci. Abstr.*, 20 (1994) 961.

[6] Cunningham, S.T., Steinman, J.L., Whipple, B., Mayer, A.D. and Komisaruk, B.R., Differential roles of hypogastric and pelvic nerves in the analgesic and motoric effects of vaginocervical stimulation in rats, *Brain Res.*, 559 (1991) 337–343.

[7] Denamur, R. and Martinet, J., Le role du systeme nerveaux de la glande mammaire dans l'entretien de la lactation, *Arch. Sci. Physiol. Paris*, 13 (1959) 271–282.

[8] Fuchs, A.R. and Dawood, M.Y., Oxytocin release and uterine activation during parturition in rabbits, *Endocrinology*, 107 (1980) 1117–1126.

[9] Greene, E.C., *Anatomy of the Rat*, Hafner Publ. Co., New York, 1968.

[10] Hebel, R. and Stromberg, M.W., *Anatomy of the Laboratory Rat*, Williams and Wilkins Co., Baltimore, 1976.

[11] Komisaruk, B.R. and Whipple, B., Complete spinal cord injury does not block perceptual responses to vaginal or cervical self-stimulation in women, *Soc. Neurosci. Abstr.*, 20 (1994) 961.

[12] Luckman, S.M., Antonijevict, I., Leng, G., Dye, S., Douglas, A.J., Russell, J.A. and Bicknell, R.J., The maintenance of normal parturition in the rat requires neurohypophysial oxytocin, *J. Neuroendocrinol.*, 5 (1993) 7–12.

[13] Moos, F. and Richard, P., Importance de la liberation d' ocytocine induite par la dilatation vaginale (reflexe de Ferguson) et la stimulation vagale (reflexe vago-pituitare) chez la ratte, *J. Physiol. (Paris)*, 70 (1975) 307–314.

[14] Ortega-Villalobos, M., Garcia-Bazan, M., Solano-Flores, L.P., Ninomiya-Alarco, J.G., Guevara-Guzman, R. and Wayner, M.J., Vagus nerve afferent and efferent innervation of the rat uterus: An electrophysiological and HRP study, *Brain Res. Bull.*, 25 (1990) 365–371.

[15] Pacheco, P., Martinez-Gomez, M., Whipple, B., Beyer, C. and Komisaruk, B.R., Somatomotor components of the pelvic and pudendal nerves of the female rat, *Brain Res.*, 490 (1989) 85–94.

[16] Peters, L.C., Kristal, M.B. and Komisaruk, B.R., Sensory innervation of the external and internal genitalia of the female rat, *Brain Res.*, 40 (1987)199–204.

[17] Randich, A. and Aicher, S.A., Medullary substrates mediating antinociception produced by electrical stimulation of the vagus, *Brain Res.*, 445 (1988) 68–76.

[18] Ren, K., Randich, A. and Gebhart, G.F., Vagal afferent modulation of a nociceptive reflex in rats: involvement of spinal opioid and monoamine receptors, *Brain Res.*, 44 (1988) 285–294.

[19] Ren, K., Randich, A. and Gebhart, G.F., Modulation of spinal nociceptive transmission from nuclei tractus solitarii: A relay for effects of vagal afferent stimulation, *J. Neurophysiol.*, 63 (1990) 971–986.

[20] Ren, K., Randich, A. and Gebhart, G.F., Effects of electrical stimulation of vagal afferents on spinothalamic tract cells in the rat, *Pain*, 44 (1991) 311–319.

[21] Steinman, J.L., Carlton, S.M. and Willis, D.W., The segmental distribution of afferent fibers from the vaginal cervix and hypogastric nerve in rats, *Brain Res.*, 575 (1992) 25–31.

[22] Stock, S. and Uvnas-Moberg, K., Increased plasma levels of oxytocin in response to afferent electrical stimulation of the sciatic and vagal nerves and in response to touch and pinch in anesthetized rats, *Acta Physiol. Scand.*, 132 (1988) 29–34.

[23] Szechtman, H., Adler, N.T. and Komisaruk, B.R., Mating induces pupillary dilatation in female rats: Role of pelvic nerve, *Physiol. Behav.*, 35 (1985) 295–301.

[24] Whipple, B., Richards, E., Tepper, M., Komisaruk, B.R., Sexual response in women with complete spinal cord injury. In D.M. Krotoski, M. Nosek and M. Turk (Eds.), *The Health Of Women with Physical Disabilities: Setting a Research Agenda for the 90's*, Paul H. Brookes Publ. Co., Baltimore, 1995, in press.