Effect of electroacupuncture pretreatment at GB20 on behaviour and the descending pain modulatory system in a rat model of migraine

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ABSTRACT
Background While electroacupuncture (EA) pretreatment has been found to ameliorate migraine-like symptoms, the underlying mechanisms remain poorly understood. Emerging evidence suggests that the brainstem descending pain modulatory system, comprising the periaqueductal grey (PAG), raphe magnus nucleus (RMg), and trigeminal nucleus caudalis (TNC), may be involved in migraine pathophysiology. We hypothesised that EA would ameliorate migraine-like symptoms via modulation of this descending system.

Methods We used a conscious rat model of migraine induced by repeated electrical stimulation of the dura. Forty male Sprague-Dawley rats were randomly assigned to one of four groups: an EA group, which received EA at GB20 following dural stimulation; a sham acupuncture (SA) group, which received manual acupuncture at a non-acupuncture point following dural stimulation; a Model group, which received dural stimulation but no acupuncture; and a Control group, which received neither dural stimulation nor acupuncture (electrode implantation only). HomeCageScan was used to measure effects on behaviour, and immunofluorescence staining was used to examine neural activation (c-Fos immunoreactivity) in the PAG, RMg, and TNC.

Results Compared to the Model group, rats in the EA group showed a significant increase in exploratory, locomotor and eating/drinking behaviour (p<0.01) and a significant decrease in freezing-like resting and grooming behaviour (p<0.05). There was a significant increase in the mean number of c-Fos neurons in the PAG, RMg, and TNC in Model versus Control groups (p<0.001); however, this was significantly attenuated by EA treatment (p<0.001). There were no significant differences between the SA and Model groups in behaviour or c-Fos immunoreactivity.

Conclusions EA pretreatment ameliorates behavioural changes in a rat model of recurrent migraine, possibly via modulation of the brainstem descending pathways.

INTRODUCTION
Migraine is a debilitating neurological disease that affects millions worldwide, including up to 12% of American and 9.3% of Chinese people. It is characterised by recurrent attacks of unilateral headache that can be aggravated by routine physical activity, resulting in reduced function. The brainstem descending pain modulatory system has been shown to play a vital role in migraine pathophysiology via effects on trigemino-vascular nociceptive information transmission and central sensitisation.

Current drug treatments include migraine-specific medications (ergotamine, 5-HT1B/1D/1F receptor agonists) and prophylactic treatments including antiepileptic drugs, lisuride, β-blockers, and ergot derivatives. However, these pharmacological agents have been associated with suboptimal efficacy, poor adherence and side effects, and have many contraindications. Overall, an efficacious clinical treatment for migraine is lacking, particularly for prophylaxis and to delay progression of recurrent to chronic migraine.

A recent review has shown that acupuncture is effective for the treatment of migraine, especially prophylaxis. Indeed, we have also found that acupuncture pretreatment is effective at decreasing the frequency of migraine attacks.

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Moreover, Gao and colleagues found that electroacupuncture (EA) is able to regulate the peripheral excitatory neurotransmitter glutamate in plasma. Nevertheless, the exact mechanisms underlying the analgesic effect of acupuncture (including pretreatment) on migraine have not yet been determined.

We hypothesised that acupuncture pretreatment would ameliorate migraine-like symptoms in recurrent migraine via modulation of the brainstem descending pain modulatory system: the periaqueductal grey (PAG), raphe magnus nucleus (RMg), and trigeminal nucleus caudalis (TNC). To test this hypothesis we chose a rat model of recurrent migraine induced by repeated electrical stimulation of the dura surrounding the superior sagittal sinus (SSS), which is an established paradigm of migraine-associated pain. The aim of the present study was to examine the effect of EA on behaviour (using HomeCageScan technology) and neuronal activation in the PAG, RMg, and TNC (by immunofluorescence staining).

**METHODS**

**Ethics statement**

All experiments were performed in accordance with the International Association for the Study of Pain guidelines and Guideline for the Care and Use of Laboratory Animals (State Council of China, 2013). The study was approved by the Beijing Institutional Review Board for Animal Experiments (Use Committee of Capital Medical University, Beijing, reference number AEEI 2015-075). All surgeries were performed under anaesthesia, and every possible effort was made to reduce suffering.

**Animals**

Male, Sprague-Dawley rats weighing 210±10 g were purchased from Vital River Laboratories. They were individually housed in a controlled environment (room temperature 23±2°C, humidity 50±10%, 12 h light-dark cycle with the lights turned on at 08:00) with food and water freely available. After 1 week of habituation, rats underwent brain surgery to establish the migraine model.

**Surgical procedures**

**Exposure of dura mater**

Rats were anaesthetised with 60 mg/kg intraperitoneal sodium pentobarbitone (Sigma-Aldrich) and placed into a stereotactic frame. To access the dura mater, the parietal bone was exposed and two cranial windows (4 mm anterior and 6 mm posterior to the bregma on the midline suture, 1 mm in diameter) were carefully made using a saline-cooled drill (78001, RWD Life Science, Shenzhen, China). The cranial windows were then opened to expose the dura mater adjacent to the SSS, as previously described.

**Electrode fixation**

A pair of tailored electrode fixtures (Beijing JiAnDeEr Ltd, China), each composed of a bipolar electrode (1.9–2.1 mm in length, 0.8 mm in diameter), a plastic holder with two screw holes and an obturator cap, were inserted into the cranial windows so that they touched the surface of the dura mater surrounding the SSS. Two stainless steel screws (M1.4×2.8 mm) were then placed into the screw holes as anchors for the dental cement (Shanghai New Century Dental Materials Co, Ltd, Shanghai, China) that was then used to stabilise the electrode fixtures. Finally the obturator cap was placed over the external stimuli line interface to prevent clogging. All surgery was performed under direct visual control using an operating microscope. Finally, penicillin (0.04 million IU/100 g, Harbin Pharmaceutical Group Co, Ltd, China) was applied to the lesion in order to prevent infection. All rats were allowed to recover for 7 days before experiments began.

**Experimental design**

After recovering from surgery, 40 animals were randomly divided into four groups: an EA group, which received EA at GB20 (Fengchi) following electrical stimulation of the dura; a sham acupuncture (SA) group, which received acupuncture (manual not EA) at a distant non-acupuncture point following electrical stimulation of the dura; a Model group, which received electrical dural stimulation but no EA; and a Control group, which received neither electrical dural stimulation nor EA (only electrode implantation). The EA, SA, and Model groups received repeated electrical stimulation using a stimulator (YC-2 stimulator Chengdu) every other day for a total of three sessions (day 1, 3, and 5). Before electrical stimulation, the EA group received EA at GB20 once a day from day 0 to day 5 for a total of six sessions. The number of rats used was based on the power calculation of a previous study. A schematic representation of the experimental protocol is given in figure 1.

**EA at GB20**

Before dural stimulation, the EA and SA group received EA/SA pretreatment from days 0 to 5, for a total of six sessions. Conscious rats were placed into tailored fixtures that exposed their heads and necks. GB20 is a commonly used acupuncture point for the treatment of migraine. Its anatomical location in rats is similar to the human, being 3 mm lateral to the centre of a line joining the two ears at the back of the head. In the EA group, two stainless steel acupuncture needles (diameter 0.25 mm; length 25 mm; Suzhou Medical Appliance Factory, Suzhou, China) were inserted bilaterally at GB20 to a depth of 2–3 mm in the direction of the opposite eye. The needle handle was then connected to an electrical stimulator (Han’s acupuncture point nerve stimulator...
HNAS-200, Nanjing) between 08:00 and 10:00 for 15 min/day. EA was given at 2/15 Hz frequency (amplitude-modulated wave) and 0.5–1.0 mA intensity (depending on the reaction of the rat). In the SA group, needles were placed bilaterally at distant non-acupuncture points (about 10 mm above the iliac crest), but no stimulation was given. Animals in the Control and Model groups were similarly placed into fixtures for 20 min, but no acupuncture was provided.

Repeated electrical stimulation of the dura
Before electrical stimulation, rats were individually placed into an observation cage (40 cm diameter, 17.5 cm height) and habituated for 20 min to minimise stress. The obturator cap was then removed from the electrode fixtures and an internal delivery electrode tip was inserted, which was connected to the current external output port of an electrical stimulator (YC-2 stimulator, Chengdu). Based on previous studies and our own optimisation of the stimulation parameters, effective dural stimuli consisted of monophasic square-wave pulses with a 0.5 ms pulse duration at 1.8–2.0 mA intensity and 20 Hz frequency, and were administered for a 15 min period every other day for a total of three sessions for rats in the EA, SA, and Model groups. Rats in the Control group were also connected to the stimulator but received no electrical stimulation.

Behavioural analysis by HomeCageScan
Spontaneous behaviour was monitored by the automated behavioural acquisition and analysis software ‘HomeCageScan’ (Clever Systems Inc, Reston, Virginia, USA). Before real/sham electrical dural stimulation, rats were acclimatised for 20 min in an individual transparent acrylic observation cage with an automatic real-time video surveillance and image analysis system, which was lit to model daytime conditions. Subsequently, animals received electrical dural stimulation for 15 min in another cage before being individually placed back into the observation cage for a 1 h recording.

The observation cage was cleaned with 10% ethanol between sessions to eliminate odour traces. Behaviours were analysed by identifying body parts such as the mouth, head, tail, forelimb, hindlimb, upper/lower back and abdomen, and using sequence data to recognise and analyse movements automatically. During the test, rats had free access to food and water.

According to previously described classifications, we divided behaviours into the following six categories:
1. Exploratory behaviour: rearing up and sniffing
2. Locomotor behaviour: turning, stretching, walking, jumping and walking slowly
3. Freezing-like behaviour (frozen, immobile posture): twitching, ‘remaining low’
4. Resting behaviour: sleeping (head rested on flexed forepaws with eyes open/closed)
5. Eating and drinking behaviour
6. Grooming behaviour: face and body grooming.

All behaviours were verified and calibrated before recording and analysis.

c-Fos immunofluorescence and image analysis
After the last HomeCageScan recording session, animals were anaesthetised with 10% chloral hydrate (15 ml/kg, intraperitoneally) and transcardially perfused through the ascending aorta with 100 ml 0.1 M phosphate-buffered saline (PBS), followed by 500 ml of 4% paraformaldehyde (PFA) in PBS. Brains were removed and postfixed overnight at 4°C in 4% PFA/PBS, then transferred to 30% sucrose/PBS for 72 h for cryopreservation. Coronal sections (25 μm thick) through the PAG, RMg, and TNC were cut using a cryostat (Leica CM3050S, Leica Inc, Wetzlar, Germany), incubated with rabbit anti-c-Fos antiserum (sc-52, 1:200, Santa Cruz Biotechnology Inc, USA) overnight at 4°C, and then treated with Cy3 goat anti-rabbit secondary antibodies (111-165-003, 1:500, Jackson ImmunoResearch Laboratories Inc, Pennsylvania, USA) for 2 h at room temperature before being mounted, dehydrated, and cover-slipped in anti-fade reagent (AR1109, Boster Bioengineering Inc, Wuhan, China).

Section images were captured using a Leica semi-automatic light microscope (Leica DM5500 B), and cells were counted in squares at 20× magnification.

Figure 1 Schematic representation of the experimental protocol. One week after surgery to implant electrodes, rats received electrical dural stimulation (or no stimulation in the case of the Control group) every 2 days from day 1 to day 5 (on days 1, 3, and 5). Electroacupuncture (or sham acupuncture) pretreatment was performed daily from day 0 to day 5 (on days 0, 1, 2, 3, 4 and 5) in subgroups of rats. Behavioural analysis was carried out using HomeCageScan immediately after dural stimulation on days 1, 3, and 5. c-Fos immunofluorescence was measured in brain tissues prepared following necropsy on day 5.

Pei P, et al. Acupunct Med. 2016;34:127–135. doi:10.1136/acupmed-2015-010840
Cell density in the PAG, RMg, and TNC was calculated by a blinded assessor using Image J software. Anatomical boundaries were determined according to a rat brain atlas.19

Statistical analysis
Data are presented as mean±SD. Groups were compared by one-way analysis of variance (ANOVA) using the Statistical Package for the Social Sciences Software (SPSS) V12.0 (SPSS Inc, Chicago, Illinois, USA). Post-hoc testing was performed using Bonferroni (homogeneity of variance) or Tamhane (heterogeneity of variance) tests. Statistical significance was defined as p<0.05.

RESULTS
Behavioural analysis
The results at baseline and following establishment of the recurrent migraine model ±EA/SA treatment are shown in table 1. Before dural stimulation, during the acclimatisation period (20 min), there were no significant differences between groups in any of the analysed behaviours (all p>0.05).

Exploratory behaviour, locomotor behaviour and eating/drinking behaviour
Across all subsequent time periods (D1–D5), rats in the Model group spent less time in exploratory behaviours (rearing up and sniffing), locomotor behaviours (turning, stretching, walking, and jumping) and eating/drinking behaviours than the Control group (p<0.001–0.011). However, by day 5, these effects were all attenuated by pretreatment with EA (p<0.001–0.006). There were no statistically significant differences between groups in the ‘walking slowly’ behaviour. There were very few significant differences between the Model and SA groups for any parameter, except for turning (D3) and walking (D1 and D5), where a greater amount of time was spent on these activities in the SA group (p=0.024, p=0.027 and p=0.001, respectively).

Freezing-like behaviour, resting behaviour, and grooming behaviour
Across all three time periods, freezing-like (twitching and remaining low) and resting (sleep) behaviours were significantly increased in the Model group compared to the Control group (p<0.001–0.002). Grooming behaviour was similarly increased on D3 and D5 (p<0.001 and p=0.005, respectively) but not D1 (p=0.887). These effects were also mitigated on D3 and D5 (but not D1) for freezing-like behaviour (p<0.001–0.047 and p=0.085–1, respectively) and at all time points for sleeping (p<0.001–0.011). Rats in the EA group spent less time grooming on D1 and D3 (p=0.042 and p=0.018, respectively) and tended to spend less time grooming on D5 (p=0.079) compared to the Model group. By contrast, there were no significant differences between the Model and SA groups for any of these parameters (p>0.05).

c-Fos immunofluorescence analysis
Representative images and the density of c-Fos-immunoreactive cells in the PAG, RMg, and TNC are shown in figures 2–4, respectively. Rats in the Model group showed greater c-Fos neuron expression than that of the Control group within the PAG (all p<0.001). In the EA group, the mean number of c-Fos positive neurons was significantly reduced in all three brain regions compared to the Model group (p<0.001), while SA had no significant effect on dural stimulation-induced c-Fos activation compared to the Model group (PAG/RMg: p=1.0; TNC: p=0.64).

DISCUSSION
The results of the present study suggest that acupuncture pretreatment at GB20 can ameliorate behavioural responses to electrical stimulation of the dura in rats, and that the positive effects may, at least in part, result from modulation of brainstem descending pathways in this model.

Acupuncture pretreatment can ameliorate the behavioural responses to migraine
The rat model of migraine used herein was developed to mimic clinical pain conditions experienced by migraineurs, based upon clinical diagnostic criteria from the International Classification of Headache Disorders (ICHD)-II and ICHD-IIβ classification including a decrease in physical activity during migraine attacks.3 20 Analysis of behavioural changes using HomeCageScan offers a new way to study migraine.18 However, it should be remembered that there are clear differences in pathophysiology between this model and the human condition, which may limit the ability to extrapolate our results.

Similar to previous studies,17 18 we found that repeated stimulation of the dura produced an increase in nociceptive behaviour, such as freezing and resting. There was also a decrease in exploratory, locomotor and eating/drinking behaviour. Collectively, these reflect the clinical symptoms of migraine attacks, which includes a reduction in routine physical activity, loss of motivation, and decreased intake of food and drink.3 4 21 Interestingly, these behavioural changes were reversed by EA pretreatment, as the EA group exhibited decreased nociceptive behaviour and increased exploratory, locomotor and eating/drinking behaviour.

It has been suggested that grooming in rats may reflect the cutaneous allodynia that migraineurs often suffer during an episode.19 Cutaneous allodynia arises as a consequence of central sensitisation of the TNC and higher structures, such as the thalamus, PAG, and RMg.5 22 It is an independent predictor of migraine progression and is closely related with imbalances in the brainstem descending pain modulatory system.22 In the current study, EA pretreatment significantly

1. [Reference 1]
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18. [Reference 18]
19. [Reference 19]
20. [Reference 20]
21. [Reference 21]
22. [Reference 22]
| Behaviour       | EA          | SA          | Model        | Control       | p Value |
|-----------------|-------------|-------------|-------------|---------------|---------|
| Rearing up      |             |             |             |               |         |
| Baseline        | 3.2±0.61    | 3.4±1.06    | 3.8±1.05    | 3.0±0.51      | 0.195   |
| D1              | 2.4±0.21    | 2.0±0.10    | 2.0±0.25    | 4.0±1.02      | <0.001  |
| D3              | 1.8±0.34    | 1.4±0.13    | 1.2±0.35    | 4.0±1.14      | <0.001  |
| D5              | 2.3±0.35    | 1.3±0.26    | 1.0±0.37    | 3.6±0.35      | <0.001  |
| Sniffing        |             |             |             |               |         |
| Baseline        | 490.7±124.17| 518.8±93.98 | 522.0±120.27| 527.5±125.92  | 0.898   |
| D1              | 589.5±36.74 | 306.4±20.87 | 247.2±39.57 | 1211.3±93.22  | <0.001  |
| D3              | 482.9±30.93 | 197.6±16.68 | 179.9±28.42 | 1074.9±102.94 | <0.001  |
| D5              | 501.9±34.56 | 145.0±10.39 | 129.4±17.74 | 1096.1±123.87 | <0.001  |
| Turning         |             |             |             |               |         |
| Baseline        | 24.3±4.96   | 22.6±5.62   | 29.8±6.08   | 22.9±7.13     | 0.039   |
| D1              | 50.7±5.04   | 25.9±4.77   | 25.8±4.69   | 66.2±9.5     | <0.001  |
| D3              | 27.2±4.55   | 15.7±1.93   | 11.1±1.43   | 64.1±8.83    | <0.001  |
| D5              | 22.7±3.47   | 13.4±2.13   | 7.0±0.96    | 50.7±6.07    | <0.001  |
| Stretching      |             |             |             |               |         |
| Baseline        | 45.5±9.74   | 42.0±5.20   | 43.5±7.64   | 38.4±5.06    | 0.178   |
| D1              | 59.3±3.2    | 56.5±5.76   | 50.4±9.48   | 99.2±10.21   | <0.001  |
| D3              | 61.9±6.71   | 50.6±5.01   | 43.6±8.75   | 100.1±10.92  | <0.001  |
| D5              | 60.4±9.04   | 47.6±4.71   | 41.2±7.8    | 107.9±13.48  | <0.001  |
| Walking         |             |             |             |               |         |
| Baseline        | 34.1±9.37   | 39.1±9.08   | 37.0±10.11  | 37.0±8.65    | 0.699   |
| D1              | 50.3±7.53   | 36.4±4.1    | 27.7±4.16   | 87.5±13.12   | <0.001  |
| D3              | 48.8±4.08   | 22.6±4.4    | 22.4±4.36   | 89.0±8.03    | <0.001  |
| D5              | 31±4.15     | 23.9±3.67   | 17.0±3.5    | 72.1±9.09    | <0.001  |
| Jumping         |             |             |             |               |         |
| Baseline        | 10.1±2.23   | 10.6±3.36   | 11.8±3.89   | 10.0±3.43    | 0.593   |
| D1              | 16.1±2.45   | 12.6±2.41   | 11.9±2.65   | 20.9±1.85    | <0.001  |
| D3              | 18.3±3.7    | 12.5±1.93   | 10.8±1.95   | 21.2±1.51    | <0.001  |
| D5              | 16.8±2.83   | 10.1±1.09   | 8.1±1.53    | 22.8±5.04    | <0.001  |
| Walking slow    |             |             |             |               |         |
| Baseline        | 21.1±3.70   | 19.5±5.73   | 17.1±5.30   | 18.0±4.51    | 0.776   |
| D1              | 51.1±6.96   | 49.1±5.76   | 46.5±9.2    | 55.3±4.9     | 0.3     |
| D3              | 48.2±7.05   | 45.9±5.01   | 44.7±9.14   | 53.0±6.22    | 0.33    |
| D5              | 48±6.49     | 45.1±5.39   | 43.7±5.71   | 52.2±7.01    | 0.179   |
| Twitching       |             |             |             |               |         |
| Baseline        | 15.0±3.01   | 17.4±2.91   | 14.8±1.85   | 15.6±2.62    | 0.150   |
| D1              | 51.9±6.91   | 61.1±8.22   | 64.6±7.77   | 40.1±9.82    | 0.001   |
| D3              | 47.8±9.08   | 68.0±5.66   | 73.9±7.51   | 36.0±5.04    | <0.001  |
| D5              | 36±5.84     | 101.7±15.62 | 106.2±11.28 | 26.8±5.42    | <0.001  |
| Remaining low   |             |             |             |               |         |
| Baseline        | 49.0±13.75  | 56.7±17.93  | 56.9±16.92  | 53.1±19.21   | 0.698   |
| D1              | 399.8±20.09 | 418.7±54.11 | 421.9±58.2  | 181.0±49.88  | <0.001  |
| D3              | 351.8±50.97 | 423.6±42.77 | 438.3±31.89 | 175.6±42.9   | <0.001  |
| D5              | 398.9±30.84 | 471.1±65.86 | 492.3±67.89 | 229.5±32.04  | <0.001  |
| Sleeping        |             |             |             |               |         |
| Baseline        | 87.6±14.77  | 78.3±7.31   | 82.8±13.57  | 83.4±13.99   | 0.456   |
| D1              | 699.8±102.83| 1101.5±271.2| 1215.2±357.9| 509.7±64.79  | 0.001   |
| D3              | 719.7±148.45| 1366.2±209.97| 1466.5±210.69| 486.2±65.56  | <0.001  |
| D5              | 937.0±95.41 | 1303.8±206.5| 1496.5±202.86| 624.9±117.77 | <0.001  |
| Drinking        |             |             |             |               |         |
| Baseline        | 6.7±2.35    | 5.8±1.56    | 6.0±2.16    | 7.6±2.99     | 0.288   |
decreased grooming behaviour, which suggests that cutaneous allodynia and central sensitisation were attenuated.

**A possible mechanism underlying the effects of EA pretreatment**

We found that EA at GB20 reversed c-Fos immunoreactivity changes in migraine-related brain areas (compared to the Model group). These results provide neurophysiological support for the assertion that the effects of acupuncture pretreatment are mediated via the regulation of imbalances in the descending pain modulatory system.

c-Fos is a protein marker of neuronal activation that has been used in diverse nociception research, including migraine. The TNC, which receives input from peripheral sensory nerves, is the second-order neuron of the trigeminovascular system. Activation of the

| EA       | SA       | Model    | Control  | p Value |
|----------|----------|----------|----------|---------|
| D1       | 50.3±4.86 | 49.0±5.75 | 48.1±3.89 | 97.5±8.25 | <0.001 |
| D3       | 39.3±4.9  | 37.8±4.41 | 33.7±3.83 | 96.5±7.45 | <0.001 |
| D5       | 43.8±3.24 | 27.1±3.56 | 24.6±3.08 | 108.9±13.28 | <0.001 |

**Eating**

|                | EA       | SA       | Model    | Control  | p Value |
|----------------|----------|----------|----------|----------|---------|
| Baseline       | 2.2±1.52 | 2.7±1.97 | 2.7±1.71 | 2.8±1.79 | 0.879   |
| D1             | 2.9±0.57 | 1.7±0.35 | 1.4±0.34 | 4.2±0.94 | <0.001  |
| D3             | 2.3±0.31 | 1.7±0.36 | 1.5±0.31 | 5.2±0.71 | <0.001  |
| D5             | 2.2±0.22 | 1.0±0.22 | 0.8±0.09 | 4.5±0.48 | <0.001  |

**Grooming**

|                | EA       | SA       | Model    | Control  | p Value |
|----------------|----------|----------|----------|----------|---------|
| Baseline       | 79.9±12.56 | 73.0±16.46 | 69.2±17.65 | 77.7±15.4 | 0.413   |
| D1             | 899.8±63.37 | 1054.8±121.15 | 1083.7±128.2 | 797.6±85.31 | 0.001   |
| D3             | 896±47.72 | 1036.9±108.54 | 1077.9±121.86 | 775.1±49.01 | <0.001  |
| D5             | 910.9±94.07 | 1041.1±152.53 | 1115.4±161.76 | 783.9±50.06 | 0.004   |

Data are time spent per behaviour per hour (s/h) and are expressed as mean±SD. Overall p values are for overall (one-way) analysis of variance comparing across the four groups at each individual time point. Mean values within a row with unlike superscripts (a, b and c) are significantly different (p<0.05) on post-hoc testing using Bonferroni/Tanham tests.

EA, electroacupuncture; SA, sham acupuncture.
TNC is regarded as a standard for activation and sensitisation of the trigeminovascular system and a reliable marker for the successful establishment of experimental models of headache.\textsuperscript{23-25} Meanwhile, TNC inhibition has proven to be predictive of therapeutic anti-migraine efficacy.

**Figure 3** Immunocytochemical distribution of c-Fos positive cells in the raphe magnus nucleus (RMg) region (A) and numbers of positive cells per 100 μm\(^2\) (B) in 40 rats that underwent implantation of electrodes followed by no stimulation (Control group, \(n=10\)) or repeated electrical dural stimulation (\(n=30\)) with no treatment (Model group, \(n=10\)), electroacupuncture pretreatment (EA group, \(n=10\)) or sham acupuncture pretreatment (SA group, \(n=10\)). Representative images show relatively sparse c-Fos labelling in the Control group (C) and EA group (F) and relatively intense c-Fos labelling in the SA group (D) and Model group (E). Scale bar=200 μm. Data are presented as mean±SD. *\(p<0.05\) vs Control group. ###\(p<0.001\) vs Model group. +++\(p<0.001\) vs SA group. py, pyramidal cell layer of the hippocampus; RP, raphe pallidus nucleus.

**Figure 4** Immunocytochemical distribution of c-Fos positive cells in the trigeminal nucleus caudalis (TNC) region (A) and numbers of positive cells per 100 μm\(^2\) (B) in 40 rats that underwent implantation of electrodes followed by no stimulation (Control group, \(n=10\)) or repeated electrical dural stimulation (\(n=30\)) with no treatment (Model group, \(n=10\)), electroacupuncture pretreatment (EA group, \(n=10\)) or sham acupuncture pretreatment (SA group, \(n=10\)). Representative images show relatively sparse c-Fos labelling in the Control group (C) and EA group (F) and relatively intense c-Fos labelling in the SA group (D) and Model group (E). Scale bar=200 μm. Data are presented as mean±SD. ***\(p<0.001\), versus Control group. ###\(p<0.001\) vs Model group. +\(p<0.05\) vs SA group. pyx, pyramidal decussation.
Numerous investigations over the past half-century have established that the descending pain modulatory system arises in the brainstem from the PAG-rostral ventrolateral medulla (RVM) circuit to the spinal and medullary dorsal horn, and can exert bidirectional effects leading to both inhibition and facilitation of pain.22,26 Electrophysiological studies by Fields and colleagues27 have demonstrated that there are two distinct groups of RVM neurons producing opposite pain modulatory effects: (1) ‘on’-cells mediating inhibition; and (2) ‘off’-cells mediating facilitation. On-cells and off-cells form the neural basis for bidirectional control by the RVM and imbalance between these two cell types is implicated in the pathogenesis and progression of pain disorders, including migraine. For migraine, the descending pain modulatory pathway that is mainly involved is believed to be the PAG-RMg circuit to the TNC. The RMg is one of the important pain modulatory nuclei in the RVM region. On-cells and off-cells of the RMg project descending fibres to the TNC, suppressing or enhancing transmission of peripheral nociceptive information to the higher brain structures.5,22

In agreement with previous studies,25,28 our results showed significant increases in c-Fos immunoreactivity within the PAG, RMg, and TNC after repeated dural stimulation, supporting the notion that activation of the PAG-RMg pathway in the descending pain modulatory system contributes to migraine pathophysiology through impaired descending inhibition and/or enhanced descending facilitation.22 Pretreatment with EA strikingly decreased c-Fos immunoreactivity within these structures. The alterations in c-Fos expression and positive behavioural changes in the EA group may reflect either an improvement of impaired descending inhibition and an enhancement of antinociception—that is, decreased descending pain facilitation (through inhibition of off-cells) and/or increased descending pain inhibition (through facilitation of on-cells). This supports previous experimental work suggesting that acupuncture analgesia is mediated in part by the descending pain modulatory system.29

CONCLUSION
Our study has shown that EA pretreatment at GB20 can attenuate behavioural responses to electrical stimulation of the dura in a rat model of recurrent migraine and can mitigate the increased expression of c-Fos neurons within the PAG, RMg, and TNC that is characteristic of this model. Overall, this evidence supports the idea that EA pretreatment can ameliorate migraine-like symptoms by altering the descending pain modulatory system; however, further molecular and electrophysiological studies are required to better understand the central mechanisms of EA treatment of migraine.

Contributors PP and LPZ conducted the experiments. PP and LL interpreted the data and wrote the manuscript. YXC and ZYQ revised the manuscript. LPW supervised the research programme and contributed to integration of the research team. All authors have read and approved the final manuscript.

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