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Modular organization of the head retraction responses elicited by electrical painful stimulation of the facial skin in humans

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HIGHLIGHTS

- We found a well-defined modular organization of the head retraction reflexes (HRRs).
- HRR are related to withdrawal strategies aimed at protecting the face.
- Central nervous system may exploit trigeminocervical reflexes synergies to simplify head and neck motor control.

ABSTRACT

Objective: To explore whether the trigeminocervical reflexes (TCRs) show a reflex receptive field organization in the brainstem.
Methods: The facial skin of 16 healthy subjects was electrically stimulated at nine sites reflecting the distribution of the three branches of the trigeminal nerve. The reflex-evoked EMG responses were measured bilaterally from the neck muscles and the head and neck kinematic reactions were detected.
Results: TCRs are site dependent. There was a vertical gradient in the magnitude of the reflex responses. EMG and kinematic reflexes were larger when evoked from ophthalmic and maxillary sites than from mandibular ones. The reflex responses exhibited a crossed right–left behavior. Stimulation of the lateral sites evoked larger reflex responses in the contralateral trapezium muscle as well as head rotation and neck bending away from the stimulated side.
Conclusion: This modular arrangement of the TCRs seems to be related to withdrawal strategies aimed at protecting the face from injuries, in accordance with the functional role that each group of muscles plays in head and neck motion.
Significance: It is likely that the CNS may exploit the neck muscle synergies revealed by the painful stimulation of the skin face in order to control the head and neck movements.

1. Introduction

Nociceptive withdrawal reflexes (NWRs) are polysynaptic, multisegmental spinal responses that generate coordinated muscle synergies aimed at withdrawing a limb from a potential source of injury (Sandrini et al., 2005). The pattern of withdrawal reflex-mediated muscle recruitment depends closely on the site of the stimulation. In animal models, Schouenborg and Kalliomäki (1990) discovered a well-defined modular organization of the neurons mediating NWRs: each muscle or group of muscles (module) was found to have a separate cutaneous receptive field corresponding to the skin region that is withdrawn when the muscle contracts. In this way, stimulation within a given receptive field induces reflex responses

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producing an optimal limb retraction from the source of the stimulation, whereas stimulation outside the receptive field may result in inhibition of a reflex in the same muscles.

Andersen and colleagues (Andersen et al., 1999) showed that a similar modular organization is also present in the human lower limb. Proximal muscles were found to have large receptive fields while more distally located muscles had smaller receptive fields covering, for example, only a part of the foot. Stimulation of the dorsolateral side of the foot evoked inversion as the dominant ankle movement along with plantar flexion (functional extension) through activation of the gastrocnemius, soleus and tibialis anterior muscles (Sonnenborg et al., 2001), whereas stimulation of the plantar side of the foot evoked dorsal flexion as the dominant ankle movement through activation of the tibialis anterior muscle. Furthermore, stimulation applied to the distal, medial sole resulted in inversion (correlated with tibialis anterior activity), whereas stimulation of the distal, lateral sole of the foot evoked eversion (Andersen et al., 1999).

Nociceptive withdrawal reflexes may also involve the head and face. Indeed, the so-called trigeminocervical reflexes (TCRs) may be considered the electrophysiological counterpart of the head retraction reflexes (HRRs) that protect the face and the head against potential injury (Sartucci et al., 1986; Serrao et al., 2003). Anatomical studies in animal models have demonstrated the presence, and role, of projections from the sensory trigeminal complex to the pedunculopontine nucleus and reticular formation nuclei. These projections have been shown to be important in head orientation in space (Meredith et al., 1992; Sasaki et al., 2004), in the coordination of the neck and proximal limbs and orienting head movements (Cowie et al., 1994; Sugiuchi et al., 2004), in postural cervical tone adaptation after external perturbation (Prentice and Drew, 2001; Drew et al., 2004), in startle reactions to unexpected auditory stimuli (Davis et al., 1982; Yeomans and Frankland, 1995), and in reactions to painful stimuli (Inglis and Winn, 1995). The existence of TCRs in healthy subjects suggests that, in humans too, there is a close functional relationship between the trigeminal sensory system and cervical motor neurons.

Since, to date, the central organization of the reflex pathway has not been studied, it remains to be established whether HRRs, like spinal reflexes, show a modular organization. Unveiling a modular organization of HRRs would provide important information on the functional organization of the trigeminal sensory pathways into the brainstem. Were such an organization to be confirmed, it could be hypothesized that the central nervous system (CNS) exploits the modules present in the brainstem to select the muscle synergies needed for specific tasks involving the head and neck (e.g. orientation and postural changes) in the same way as it exploits the modules involved in movement of the limbs (Bizzi et al., 2000).

The main hypothesis underlying the present study was that cutaneous nociceptive stimulation of a localized facial area preferentially activates a specific group of neck muscles, i.e. those able to produce the optimal withdrawal response. Given the importance of the eye area, we expected reflexes evoked by stimulation of the skin innervated by the trigeminal ophthalmic branch and by the maxillary branch serving the eye area to be more pronounced than those evoked by the trigeminal mandibular branch. Furthermore, the pattern of muscle responses may differ upon stimulation of facial skin in midline as opposed to lateral areas. It was envisaged that stimulation of midline areas would induce neck–head retraction responses, whereas stimulation of lateral areas would evoke neck bending and/or head rotation responses, according to the side of stimulation.

To test these hypotheses, the modulation pattern of major neck muscle responses following bilateral nociceptive trigeminal nerve stimulation was assessed. Nerves were stimulated at different facial skin sites corresponding to the ophthalmic, maxillary and mandibular innervation areas.

2. Methods

2.1. Participants

Sixteen right-handed healthy subjects, aged 23–41 years, 10 males and 6 females, gave their written informed consent and participated in this study. The study conformed to the standards set by the latest revision of the Declaration of Helsinki. In particular, none of them had any uncorrected visual, as assessed with Snellen visual acuity test, or auditory, as assessed with pure tone audiometry test, deficits. The experimental procedures had local ethics committee approval.

2.2. Technique

2.2.1. Electrical stimulation

We used an electrical stimulator (Digitimer DS7A, UK) synchronized to a data acquisition and analysis interface (CED Power 1401, Cambridge Electronic Design, UK).

Male subjects were required to shave several hours prior to the experiment to reduce the bias of differences in skin thickness and resistance due to facial hair.

The skin of the face was cleaned with alcohol and was stimulated through standard Ag/AgCl surface bipolar electrodes (Medelec, Oxford, UK; diameter 1 cm, 1 cm inter-electrode distance) applied to nine different sites. The sites were chosen according to the distribution of the three branches of the trigeminal nerve (ophthalmic, maxillary and mandibular) and thus showed a mediolateral arrangement (see Fig. 1). For each electrode position, the electrode was moved slightly in case the evoked sensation indicated direct nerve stimulation (with the sensation radiating to the innervation territory of the nerve branch). Trains of electrical stimuli composed of three pulses, each of 1 ms duration (inter-pulse interval 5 ms), were used to evoke the TCRs (Serrao et al., 2010). Individual pain thresholds (PTs) were assessed at each stimulation site using a staircase method that consisted of three series of ascending and

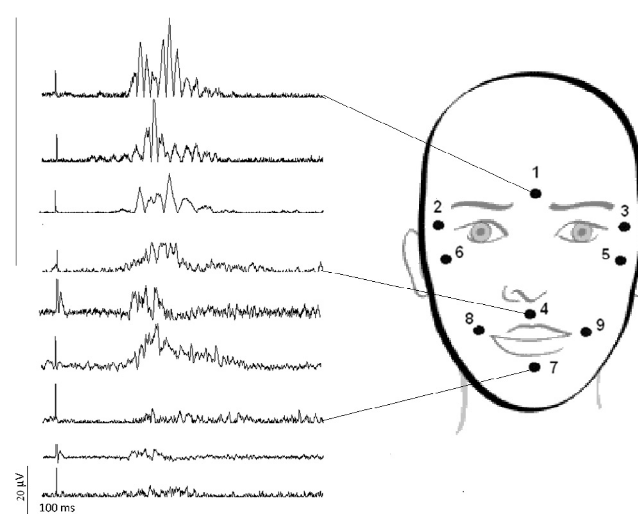

Fig. 1. Experimental setup. Facial skin stimulation sites. Trigeminocervical responses were evoked by distributed electrical stimulation of the face using surface electrodes at distinct locations. Three midline (glabella, supra- and infra-lips; 1, 4, 7) and six lateral (two supra-orbital and two infra-orbital and two at lip angles) skin sites were stimulated. The location of the sites reflected the anatomical distribution of the three branches of the trigeminal nerve (ophthalmic, maxillary and mandibular). Examples of trigeminocervical reflexes in the rectified EMG signals are depicted.