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Research report

Gradual enlargement of human withdrawal reflex receptive fields following repetitive painful stimulation

Ole K. Andersen*, Erika G. Spaich, Pascal Madeleine, Lars Arendt-Nielsen

Department of Health Science and Technology, Center for Sensory-Motor Interaction, Aalborg University, Fredrik Bajers Vej 7, D3, DK-9220 Aalborg, Denmark

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Abstract

Dynamic changes in the topography of the human withdrawal reflex receptive fields (RRF) were assessed by repetitive painful stimuli in 15 healthy subjects. A train of five electrical stimuli was delivered at a frequency of 3 Hz (total train duration 1.33 s). The train was delivered in random order to 10 electrode sites on the sole of the foot. Reflexes were recorded from tibialis anterior, soleus, vastus lateralis, biceps femoris, and iliopsoas (IL). The RRF changes during the stimulus train were assessed during standing with even support on both legs and while seated.

The degree of temporal summation was depending on stimulation site. At the most sensitive part of the RRF, a statistically significant increase in reflex size was seen after two stimuli while four stimuli were needed to observe reflex facilitation at less sensitive electrode sites. Hence, the region from which reflexes could be evoked using the same stimulus intensity became larger through the train, that is, the RRF was gradually expanding. Reflexes evoked by stimuli four and five were of the same size. No reflex facilitation was seen at other stimulus sites outside the RRF. In all muscles except in IL, the largest reflexes were evoked when the subjects were standing. In the ankle joint, the main withdrawal pattern consisted of plantar flexion and inversion when the subjects were standing while dorsi-flexion was prevalent in the sitting position. Up to 35° of knee and hip flexion were evoked often leading to a lift of the foot from the floor during standing. In conclusion, a gradual expansion of the RRF was seen in all muscles during the stimulus train. Furthermore, the motor programme task controls the reflex sensitivity within the reflex receptive field and, hence, the sensitivity of the temporal summation mechanism.

Theme: Motor systems and sensorimotor integration
Topic: Reflex function

Keywords: Modular organisation; Temporal summation; Wind-up; Posture

1. Introduction

In the pain system, a gradual build up in pain intensity has been observed following repetitive nociceptive stimulation at a frequency higher than 0.3 Hz [17] and up to 20 Hz [7]. It probably reflects integration of excitatory post-synaptic potentials at the spinal level and is often termed temporal summation [17]. An indirect measure of the spinal integration is the nociceptive withdrawal reflex. In humans, stimulation of a single position on the dorsum of the foot evokes a withdrawal reflex in the hamstring muscles that is sensitive to variation in stimulus intensity and stimulus frequency [7]. There is a high correlation between reflex build up and induction of pain indicating that activation of nociceptive fibres is needed for this spinal integration to occur [7].

Nociceptive withdrawal reflexes are modularly organised meaning that each muscle has a unique cutaneous reflex receptive field (RRF) [2,19]. Stimulation within this receptive field may evoke a reflex in the muscle, and the muscle contraction will lead to a withdrawal of the exact stimulation site. In other words, there is a strong relationship between the cutaneous reflex receptive field and the

* Corresponding author. Fax: +45 98154008.
E-mail address: oka@hst.aau.dk (O.K. Andersen).

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biomechanical function of the muscle. Several muscles have overlapping RRFs whereby the reflex movement is the net result of the activated muscles. The encoding of the RRF probably takes place in the deep dorsal horn and putative receptive field encoders are primarily wide-dynamic range (WDR) neurones [23]. Interestingly, wind-up primarily occurs in deep dorsal WDR neurones following C fibre activation [20] and it correlates with withdrawal reflex activity [9,27].

The sensitivity of the RRF is high within the primary focus of the RRF and gradually shrinks toward the border of the RRF [19]. In addition, the latency of the reflexes is shortest in the RRF focus and longer towards the border of the RRF in animals [19] and in humans [3] indicating graded RRF sensitivity. It is therefore hypothesised that repetitive stimulation within the focus of the RRF may lead to robust temporal summation while stimulation in the periphery evokes less temporal summation at identical stimulus intensities.

In a recent study, the RRFs for several muscles were depicted during standing [4]. At the ankle, the reflex gain of extensor/flexor reflexes was altered depending on the present motor task as reflexes in the soleus muscle play an inferior role in relaxed conditions [2], but dominated while standing [4]. Hence, in the reflex pathway, proprioceptive input and/or the ongoing motor control programme modulate the basal reflex receptive field encoding. However, it is unknown to what extent the spinal temporal summation is varying across the stimulation sites in different postures.

The aim of the present study was (1) to investigate if the temporal summation in nociceptive withdrawal reflex modules depends on stimulation site and (2) to what extent a functional motor task govern this spinal integration by assessing the RRF during both sitting and standing conditions.

2. Materials and methods

15 volunteers (nine males and six females, mean age 24.5 years, range 20–32 years) participated in the study. Written informed consent was obtained from all subjects, and the Helsinki Declaration was respected. The study was approved by the local ethical committee (approval number VN2005/2).

Reflexes were recorded during two different sessions. In one session, the subjects were sitting in an elevated chair with knees and hips flexed 90° and the lower leg free to swing. In another session, the subjects were standing in symmetrical position with even support on both legs. To assess the effect of the repetitive stimulation, RRFs were assessed by EMG recordings supported by net kinetic and kinematic reflex responses acquired by force and joint ankle measurements in order to assess any functional variation in the reflex organisation between the two postures.

2.1. Electrical stimulation

Ten surface electrodes (15 × 15 mm, Ambu type 700, Denmark) were mounted in a non-uniform grid on the sole of the right foot (Fig. 1). A thick stratum corneum layer was ground off using a skin file while ensuring that live tissue was not damaged in order to reduce the bias of varying skin thickness. For each electrode position, the electrode was moved slightly in case the evoked sensation indicated direct nerve stimulation (with the sensation radiating to the distal foot). A common anode (7 × 14 cm electrode, Pals, Axelgaard Ltd., Fallbrook, California, USA) was placed on the dorsum of the foot. The use of a large electrode placed on the dorsum of the foot ensured that the stimulus was always perceived as coming from the sole of the foot. Each stimulus consisted of a constant current (Noxitest, Aalborg, Denmark) pulse train of five individual 1 ms pulses delivered at 200 Hz. By use of a computer controlled electrical relay, a stimulus was delivered to one of the ten electrodes. In all tests, a train of five stimuli at the same stimulus intensity was delivered with a frequency of 3 Hz. Each stimulus position was tested with five stimulus trains during sitting and during standing resulting in a total of 100 stimulus trains. To decrease habituation, the interval between two trains was between 15 s to 20 s depending on the time required for scoring the pain intensity and regaining balance during the standing session.

2.2. Kinetics—force platforms

In the standing session, the subjects were standing barefooted in a normal posture on two force platforms (AMTI, type OR6–7), which measured the resulting ground reaction forces in the mediolateral (ML), anteroposterior (AP), and vertical directions, and reaction moments around the sagittal and frontal axes of the force platforms. The force platform signals were amplified 4000 times, low-pass filtered (10 Hz second order), and sampled at 1000 Hz. The subjects were asked to position their feet in a relaxed, symmetrical position. The outlines of the feet were marked on the force platforms to make sure that the volunteers stood in the same position throughout the experiment. The subjects looked forward at an eye-level feedback monitor with their arms alongside the body.

2.3. Postural feedback

Visual feedback was provided to the subjects to ensure a standardised posture. Based on the force-platform signals, eight arrows separated by 45° were depicted for both feet on a computer monitor placed right in front of the volunteers. With the subjects in balance, baseline values of forces and moments were captured. During the experiment, an arrow was turned on when the centre of pressure (CoP, see definition later) of one of the feet was