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Modulations of interlimb and intralimb cutaneous reflexes during simultaneous arm and leg cycling in humans

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Abstract

Objective: We investigated to what extent intralimb and interlimb cutaneous reflexes are altered while simultaneously performing arm and leg cycling (AL cycling) under different kinematic and postural conditions.
Methods: Eleven subjects performed AL cycling under conditions in which the arm and leg crank ipsilateral to the stimulation side were moved synchronously (in-phase cycling) or asynchronously (anti-phase cycling) while sitting or standing. Cutaneous reflexes following superficial radial or superficial peroneal nerve stimulation (2.0–2.5 times radiating threshold, 5 pulses at 333 Hz) were recorded at 4 different pedal positions from 12 muscles in the upper and lower limbs. Cutaneous reflexes with a peak latency of 80–120 ms were then analyzed.
Results: The magnitude of interlimb and intralimb cutaneous reflexes in the arm and leg muscles was significantly modulated depending on the crank position for the relevant limb (phase-dependent modulation). A significant correlation between the magnitude of the cutaneous reflex and background EMG was observed in the majority of muscles during static contraction, but not during AL cycling (task-dependent modulation). No significant difference was found in comparisons of the magnitude of intralimb and interlimb cutaneous reflexes obtained during in- and anti-phase AL cycling. Qualitatively, the same results were obtained during AL cycling while sitting or standing. In addition, the modulation of cutaneous reflexes in arm muscles was identical among in-phase, anti-phase and isolated arm cycling. Results were the same for leg muscles.
Conclusions: Cutaneous reflexes in arm muscles are little influenced by rhythmic movement of the legs and vice versa during AL cycling. It is likely that neural components that control interlimb reflexes are loosely coupled during AL cycling while sitting or standing.
Significance: Our results provide a better understanding of the coordination between the upper and lower limbs during rhythmic movement.

Keywords: Interlimb coordination; Cutaneous reflex; Cycling; Human

1. Introduction

Around a century ago, original physiological evidence indicating the possible contribution of neural connections subserving interlimb and intralimb reflexes to locomotion was provided by Sir Charles Sherrington (Sherrington, 1910; Sherrington and Laslett, 1903). Later, it was shown in the cat that stimulation of the cutaneous nerve produces general flexor excitation with the exception of muscles directly beneath the stimulated region of the skin (local sign, Hagbarth, 1952), and that contact between the dorsum of the hindlimb paw and an obstacle during the swing phase of locomotion evokes coordinated ankle flexion and knee extension in an attempt to avoid tripping (Forssberg et al., 1975). The latter reflex pattern has been termed the 'stumbling corrective reaction' and also occurs during human walking (Van Wezel, 1997; Zehr et al., 1998). To date, intralimb cuntaneous reflexes were demonstrated to

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have task dependency (phasic locomotor vs. tonic maintained activity), intensity dependency (noxious vs. nonnoxious stimulation), load dependency, phase dependency (swing vs. stance), and laterality dependency (ipsilateral vs. contralateral effects) (review see, Dietz, 2002; Dietz and Duysens, 2000; Zehr and Duysens, 2004).

Stimulation of the skin was shown to produce a widespread reflex effect in various motoneuron pools (for review, see Dietz, 2002; Zehr and Duysens, 2004). For example, coordinated muscle activation in intra- and intersegments following stimulation of the skin during on-going locomotor activities was shown in the cat (Miller et al., 1975; 1977; Schomburg et al., 1977). Stimulation of cutaneous nerves in the human median and sural nerves also evokes reflex changes in the upper and lower limbs (Delwaide and Crenna, 1984; Kearney and Chan, 1979; 1981). Recent advances in the study of interlimb reflexes in humans have provided ample evidence that they are crucial for generating rapid compensatory movements in remote limbs in response to a sudden disturbance of limb movement during various locomotor activities (Dietz, 2002; Dietz et al., 2001; Duysens and Tax, 1994; Haridas and Zehr, 2003; Wainner et al., 2001; Zehr et al., 2003; 2001a; Zehr and Duysens, 2004). The magnitude of interlimb reflexes during rhythmic movement shows strong phase modulation and task-dependent modulation compared to static movement, suggesting the possible contribution of a central pattern generator (CPG, for review, see Dietz, 2002; Zehr and Duysens, 2004).

Rhythmic bipedal cycling is a powerful tool for investigating human locomotor systems (Brooke et al., 1997; Zehr et al., 2001b; Zehr and Duysens, 2004). In leg muscles, cutaneous reflexes following sural nerve stimulation are modulated in a phase-dependent manner depending on the biomechanical function of the limb muscles during cycling (Mileva et al., 2004). Also, the Hoffmann (H-) reflex and cutaneous reflexes evoked in forearm muscles are dependent on the movement phase during rhythmic arm movement (Zehr and Kido, 2001; Zehr et al., 2003). Furthermore, the size of the reflexes is proportional to the background EMG (B.EMG) during the stationary condition but not during cycling (Zehr and Kido, 2001; Zehr et al., 2001a, b). These results suggest a contribution of CPGs to the regulation of locomotor activity not only in the lower limbs but also in the upper limbs. Thus, rhythmic bipedal cycling can be used as a model for investigating the function of a CPG in humans.

The presence of interlimb reflexes was shown in spinal cord injured subjects (Calancie et al., 1996; 2002), indicating that propriospinal pathways coupling the cervical and lumbosacral enlargements of the spinal cord contribute to interlimb coordination (Dietz et al., 2001; Frigon et al., 2004; Haridas and Zehr, 2003; Wannier et al., 2001; Zehr et al., 2001a). We hypothesized that if there exists a strong neural link between the upper and lower limbs, interlimb and intralimb cutaneous reflexes would show phase- and task-dependent modulations when human subjects simultaneously performed arm and leg cycling (AL cycling). In addition, cutaneous reflexes are differently modified during AL cycling from that during arm or leg cycling alone and during two types of AL cycling in which the upper and lower limbs are rotated synchronously (in-phase) or asynchronously (anti-phase). Furthermore, it is possible that cutaneous reflexes are modulated if AL cycling is performed under the different postural conditions of sitting and standing because the magnitude of cutaneous reflexes is known to strongly depend on the motor task (Burke et al., 1991; Do et al., 1990; Duysens et al., 1990; Komiyama et al., 2000; Thoumie and Do, 1996). Therefore, in the present study, interlimb and intralimb cutaneous reflexes in the upper and lower limb muscles following nonnoxious electrical stimulation of superficial radial (SR) and superficial peroneal (SP) nerves were examined during in-phase and anti-phase AL cycling in sitting and standing positions.

2. Methods

2.1. Subjects

Eleven male volunteers aged 22–29 years participated in this study. All subjects gave their informed consent according to the Declaration of Helsinki before participating in the experimental procedures. No subject had a neurological deficit nor had been involved in any resistance training programs. This study was approved by the local ethics committee.

2.2. Nerve stimulation

Electrical pulses were delivered from a constant current stimulator (SS-100, Nihon Kohden, Tokyo, Japan) controlled by a pulse generating system (SEN7201, Nihon Kohden). Cutaneous reflexes were evoked by applying electrical stimulation via rectangular pulses 1 ms in duration to the right SR and SP nerves, respectively. Both nerves were stimulated with trains of 5 pulses at 333 Hz. Ag/Ag–Cl disk electrodes (ϕ 1 cm, NE-101, Nihon Kohden) for SR nerve stimulation were placed on the dorsal surface of the right forearm just proximal to the radial head. The same electrodes were used to stimulate the SP nerve and were placed on the anterior surface of the right leg just near the crease of the ankle joint. The threshold of stimulation (radiating threshold; RT) was defined as the stimulus voltage at which the subject reported just being able to distinctly feel radiating paresthesia occurring along the dorsal surface of the hand towards the index finger and thumb (SR nerve) and dorsal surface of the foot towards the first toe (SP nerve). The RT was determined when the crank position for both the arm and leg was located at 12 o'clock. The stimulation intensities were set at $2.0 \sim 2.5 \times$RT and