Abstract  This study examines the impact of peripheral nerve block, that is, the elimination of tactile feedback on synchronization performance. In a tapping experiment in which subjects were instructed to tap in synchrony with an auditory pacing signal, three different tasks were studied under conditions with and without peripheral nerve block: standard tapping with tactile contact, isometric tapping, and contact-free tapping. In addition, the maximum tapping rate was registered both with and without peripheral nerve block. It was found that the anticipatory error, usually observed in synchronization tasks, was affected by the peripheral nerve block in the standard tapping and the isometric tapping task. In both tasks, local anesthesia led to an increase in asynchrony between the pacing signal and the tap. Performance remained unimpaired in those tasks in which tactile information was assumed to play a minor role (maximum tapping rate and contact-free tapping). The results clearly demonstrate the importance of tactile feedback for the timing of movements. The predictions of a model assuming a strong correlation between the amount of sensory feedback and the size of the negative asynchrony in synchronization tasks were examined and discussed.

Keywords  Sensorimotor synchronization · Tapping · Timing · Motor control · Peripheral nerve block · Human

Introduction

There are numerous scientific studies on planning and control of movements. Likewise, there are a number of sensory studies that address psychophysical issues pertaining to perception. However, there has been considerably less attention devoted to the nature of the interface between the input and output systems: how sensory inputs are used to create action programs, and how actions intervene in framing perceptual goals. This paper is concerned with the first question by studying the influence of afferent and reafferent information on the timing of movements.

The contribution of somatosensory information to movement control has always been a major concern of physiological studies and has recently been reappraised (Gandevia et al. 1992). In particular, the contribution of kinesthetic reafferences to the timing of movement sequences has been demonstrated in man (Cordo et al. 1994). Studies on deafferented patients suffering from polyneuropathy, affecting selectively the contingent of the large myelinated sensory fibers (thus suffering all cutaneous and proprioceptual information, but leaving the motor system intact), have shown that some reafferent signals generated in the moving body segment were mandatory to organize the precise timing of self-induced efferent commands required to synchronize the command with another event (Bard et al. 1991, 1992; Billon et al. 1996; LaRue et al. 1995; for a review on motor control in humans with large-fiber sensory neuropathy, see Sanes 1990).

In the present study, we examine the contribution of tactile afferent information to the timing of sequential finger movements by studying a sensorimotor synchronization task. In synchronization tasks, subjects are asked to tap with a finger in synchrony with a periodical sequence of auditory clicks, that is, to time their actions so as to coincide with certain events. It is commonly observed that people are not very exact in synchronizing; typically, the tap leads the click by approx. 20–50 ms (see Aschersleben and Prinz 1995, 1997; Aschersleben et al. 2000a; Fraisse 1980; Mates et al. 1992; O’Boyle 1997; Vos et al. 1995; for a recent overview, see Aschersleben 2000a). Recent accounts of this so-called negative asynchrony or anticipatory error have focused on the way people might cognitively control their performance in synchronization tasks. In particular, we have suggested that synchrony is not only controlled by, but also established at, a central representational level, where both stimuli and actions are represented in terms of their sensory effects (Aschersleben and Prinz 1995, 1997; Aschersleben et al. 2000a;
Prinz 1997). Therefore, action control in synchronization tasks in not so much concerned with the temporal relationship between the auditory input and the motor output but with realizing synchrony between perceived click and perceived tap. If so, the time it takes to perceive the click and the tap becomes crucial, the more so as auditory and kinesthetic-tactile stimulation can be assumed to differ in processing speed. In fact, as the temporal delay between actual and perceived click is shorter than the delay between actual and perceived tap, the actual tap must precede the actual click to achieve synchrony between the perceived events at a central level, hence the negative asynchrony between click onset and overt tap.

There are two models that are based on the assumptions (1) that the corresponding central representations of click and tap’s sensory effects are brought to coincidence and (2) that the central representation of the tap is based on the somatosensory feedback arising from the finger movement and the touch of the key. However, these two accounts differ with respect to their assumptions on how differences in processing time are produced. According to the so-called Paillard-Fraisse hypothesis, differences in nerve conduction times between click and tap on their way to their central representation are responsible for the anticipatory error (Aschersleben and Prinz 1995, 1997), while the “sensory accumulator model” (SAM; J. Gehrke, unpublished work; Aschersleben et al. 2000a) assumes that clicks and taps differ with respect to the amount of sensory evidence required for central coding.

Thus, unlike the SAM, according to the Paillard-Fraisse hypothesis the cause of asynchrony is to be found at a peripheral level. As it takes more time for sensory information (resulting from the tactile and kinesthetic feedback of the tap) to travel from the fingertip to the brain than from the ear to the brain, the tap has to lead the click to achieve temporal coincidence of the two central codes (Aschersleben and Prinz 1995, 1997; Fraisse 1980; Paillard 1949). Therefore, any change in the time between the tap and its central representation by manipulation of conduction delays should affect the asynchrony in a predictive manner: An increasing conduction time should lead to an increase in the amount of the anticipatory error. This view presupposes that the timing of the tap is not only determined by the first feedback component that is available at a central level. On the contrary, contributions from various feedback modalities are assumed to be integrated and to enter into a common gestalt. Only the timing of this gestalt as a whole determines the timing of the tap (see Fraisse et al. 1958 for a related notion).1

While the Paillard-Fraisse hypothesis stresses the role of delays derived from conduction times in afferent pathways, the SAM assumes that processing times needed to generate a central representation of peripheral events might also play a role in the observed asynchrony. The model assumes that an external event to be experienced and timed would necessitate its central representation as an experienced neural entity. The processing times necessary for generating this neural state would be threshold dependent, and this would change depending on the density of afferent neural signals generated by the physical events. Hence, the model is based on the assumption of an accumulation function whose steepness determines the time elapsed between an external event and its central representation. Consequently, the auditory pacing signal used in the synchronization task has a steeper accumulation function as compared to the tap; a negative asynchrony is obviously expected (Aschersleben et al. 2000a). A relevant factor influencing the size of the anticipatory error would then be the density of afferent signals arriving at a central level. The more afferent signals (in a unit of time) the earlier a threshold should be reached.

The aim of this study was, first of all, to demonstrate a contribution of somatosensory feedback to the timing of the tap in a sensorimotor synchronization task. The second aim of the study was to distinguish between the two hypotheses described above that make different assumptions concerning the processes influencing the timing of central representations. We can answer both questions by studying the influence of peripheral nerve block on the performance in a synchronization task. By anesthetizing the index finger that performed the tapping movement, we assumed that we suppressed tactile reafferent information without disturbing the reafferent discharge of the joint and muscle receptors.2 Moreover, in terms of conduction times, by eliminating tactile feedback we supposed that the slower feedback component of the reafferent volley was eliminated, whereas the faster kinesthetic feedback component remained unimpaired (Strichartz 1976).

Figure 1 shows the predictions of the two models for digital nerve block. Two panels are shown for each model: activation volleys (upper panels) and accumulation functions reflecting their integrals (lower panels). According to the Paillard-Fraisse model, the critical computations are performed on the activation volleys (whereas the accumulation functions are irrelevant). Conversely, in the SAM model, the activation volleys play no role and the critical computations are performed on the accumulation functions. This difference is reflected in the breadth of the corresponding lines.

---

1 This view has gained empirical support from experiments in which additional auditory feedback was presented to the subjects each time the finger touched the key. As this feedback tone had the same conduction delay as the auditory pacing signal, the asynchrony should disappear under an assumption, assuming that the tap is represented by the first feedback component available. In a series of experiments, it has been shown that the asynchrony is significantly reduced under those conditions but still remains different from zero (Aschersleben and Prinz 1995, 1997; Mates and Aschersleben 2000; Mates et al. 1992; O’Boyle and Clarke 1996), supporting the assumption of a common gestalt.

2 However, this does not mean that subjects do not have any information about their finger movement. First, information from the kinesthetic feedback is still available. In addition, Edin and Johansson (1995) have demonstrated that even after digital nerve block skin deformation related to digit movements could provide an excellent signal about finger movements.